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Development of an Inventory Management Strategy to Determine Stock Levels and Service Levels for COTECMAR

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June 2012

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The main objective of this research is to determine the best approach for managing inventory at COTECMAR, a shipyard in the Colombian Navy. The distinct nature of demand for items required in building and repair of ships, the uncertainty surrounding the repair needs, and the broad range of customers being served make managing inventory at a shipyard uniquely challenging.

The project started with a review of selected inventory management strategies and theories. Thereafter, we identified a small sample of items, collected demand data for these items, and analyzed that data to better understand the drivers of demand. We concluded that (1) the items needed in shipbuilding and other special projects are dependent demand items that are better managed through Materials Requirements Planning (MRP) approach, and (2) the items needed in repairs are independent demand items better managed through the Economic Order Quantity (EOQ) approach.

Accordingly, we collected and analyzed additional data, such as cost factors, to perform the necessary EOQ and service level calculations for selected items to illustrate the methodology we propose in this research. We conclude the paper with several specific recommendations for the management at COTECMAR and provide suggestions for carrying out future research.

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DEVELOPMENT OF AN INVENTORY MANAGEMENT STRATEGY TO DETERMINE STOCK LEVELS AND SERVICE LEVELS FOR COTECMAR

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Submitted in partial fulfillment of the requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

BG	Bocagrande
COTECMAR	Science and Technology Corporation for the Development of the Maritime, Naval and River Industry
COP	Colombian Pesos
DBV	Distribution by Value
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
MA	Mamonal
MRP	Material Requirement Planning
PO	Purchase Order
ROP	Reorder Point
SKU	Stock Keeping Unit
SL	Service Level
WH	Warehouse
WOI	Weeks of Inventory

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– LT Luis Villegas Portocarrero

–1st LT Saud Mohamed AlKhan

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–LT Luis Villegas Portocarrero

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–1st LT Saud Mohamed AlKhan

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I. INTRODUCTION

This project pertains to inventory management in COTECMAR,[1] the largest shipyard in Colombia, which employs around five hundred full-time employees and about two thousand part-time employees. COTECMAR industrial activities include ship repair, ship building, design, and mechanical and electrical engineering. It provides all the services required by the Navy fleet, as well as civilian customers around the world, which accounts for approximately two hundred ships per year. Out of these two hundred ships, about ten are shipbuilding projects, and the rest are repair projects. COTECMAR holds about ten thousand items that are used regularly; however, the item database accounts for more than fifty thousand items due to items that are used in rare circumstances or were used only once.

This chapter gives a brief description of the corporation and the industry that our report focuses on. We discuss the general research topic in the background section. In the next section, we explain the objective of our research and address the primary and secondary questions that this report includes. Finally, we conclude the chapter with an explanation of the organization of this report, describing the general steps that are used in the report.

A. BACKGROUND

The Science and Technology Corporation for the Development of the Maritime, Naval and River Industry (COTECMAR) was born as a shipyard in 1951 to meet the needs of the Colombian Navy. In the early 1990s, the shipyard was closed due to budgetary issues. In 2000, the shipyard was opened again with a new legal form that allows the shipyard to generate its own profits and reinvest them in science and technology, which includes activities such as research, development, innovation, training, education, etc.

[1] COTECMAR is the acronym for its short name in Spanish *Corporación Técnica Marítima* (Maritime Technical Corporation).

COTECMAR is located in Cartagena, a city on the Caribbean coast of Colombia. COTECMAR has two yards: one is located inside the Caribbean Naval Base, the Bocagrande Division Plant; and the other yard is located in the industrial zone of the city. This latter yard hosts the Mamonal Division Plant, which performs repairs, and the Shipbuilding Division Plant. There are two warehouses, one in the Bocagrande plant and one in the Mamonal plant.

A shipyard is a kind of industry that demands fast response in the services provided due to the high opportunity cost of having a ship on the dock rather than at sea. However, the needs of each ship vary, making it difficult to estimate the demand of materials or parts that are going to be needed in the repair process. One of the biggest goals of supply chain management theories and best logistic practices is to reduce the time in the operations, in order to increase the service level as well as reduce unseen costs that are adding weight to the process. Any unnecessary step makes the process slow and does not generate value in a production line.

Supply chain management and operations management practices include some approaches to optimize inventory levels, reduce costs, improve the response to clients, and minimize risk along the supply chain. However, some of the literature and the theory we study in these subjects is related specifically to production lines with distinct inventory items that have uncertainty in demand. Other literature is related to different kinds of industries with problems dealing with randomness in the inventory they manage. But, the nature of the shipyard makes inventory management an especially challenging task, due to large varieties of items needed, high variation of the demand, and uncertainty, among other factors.

There is a great deal of relevant information in inventory management literature. Some of the literature addresses the classification of goods according to some characteristics of cost and risk in their acquisition. Other literature addresses the classification of goods in a different way. Some authors address inventory management depending on the demand, if it is known or unknown; other authors address inventory management based on different factors such as externalities, vendor agreements, lead times, and multiple strategies. Finally, some references have mathematical models for different kinds of data, while other references use algorithms with other sources of data to determine the same levels of stocks, frequencies, times, cycles, and other information related to inventory management. Throughout this project, we gather theories, equations, models, and practices to recommend an approach using the variables related to an industry such as shipbuilding.

Our findings are useful to make good recommendations that are feasible. These recommendations are not only useful for a shipyard but also for military maintenance departments and other businesses such as car repair and house maintenance, among others.

B. OBJECTIVE

The central objective of this project is to determine the best methods for determining stock levels and service levels of COTECMAR inventory. This project will help decision makers to better understand the characteristic of different kinds of inventory. As a result, it will enable them to make decisions on inventory management and logistics practices so as to improve efficiency in the supply chain. Efficiency in the supply chain will help reduce costs and delays, which will contribute to a higher profit margin on each project. Efficiency also can help strengthen the company's image by improving customer service and satisfaction. A better image and credibility will position the company in a competitive standing amongst world-class shipyards.

The focus of this research uses inventory management strategies prevalent in the best logistical practices of supply chain management and operations. According to the characteristics of these inventory strategies and the kind of data needed for their implementation, we will evaluate their suitability for a repair industry such as shipbuilding. The objective of this project is to recommend a suitable approach for managing inventory by taking a small sample of items from COTECMARs inventory and analyze it.

Some primary questions arise when trying to achieve these goals:

1. What are the optimal Inventory Stock Levels for a sample of items in a repair Industry such as shipbuilding?
2. What are the optimal Service Levels for a sample of items according to the characteristics of the inventory?

To be able to answer the primary questions, the following secondary questions must be addressed:

1. What are some recognized Inventory Management Strategies used in supply chain and operations management?
2. What Inventory strategy is suitable for a shipyard?
3. What mathematical models or algorithms are utilized in the selected strategy?
4. What data is needed for the selected strategy?
5. And how do we apply the strategy to the data?

C. ORGANIZATION OF REPORT

To develop this MBA Project, first we study Inventory Management Strategies used in recognized supply chain and operations management methodologies. These methodologies include inventory classification models, inventory management models, and methods for determining service levels. The classification models we apply are the Kraljic model and the ABC model. Furthermore, we use probabilistic model to calculate reorder quantity, reorder point, and safety stock. These three parameters are essential in inventory management decision making. Moreover, we use different approaches to determine customer service levels based on the item parameters.

Second, we collect data from the COTECMAR Shipyard to be analyzed using a suitable Inventory strategy or model for this industry. This is applied according to the assumptions of each model. Third, we analyze and determine optimal stock levels and optimal service levels on a small sample of items in each category. This enables us to make inferences about each category. Finally, we conclude with recommendations for the implementation of proposed inventory strategies in the shipyard to manage the inventory in an efficient manner.

II. INFORMED FOUNDATION

In this second chapter of the report, we explain the overall procedures used to apply inventory strategies. This chapter of the report is based solely upon the review of literature. First, we describe the classification models in order to group the different kind of items in our inventory. This is necessary to make decisions based on the characteristics of each group. Then, we explain inventory management models that may be applied to the inventory depending on each classification. Most of the data needed to use these models exists in the collected data; however, there is another parameter needed, which is the service level. The service level, in some cases, is given arbitrarily; however, to be more accurate, it is better to calculate it using the existing information. So, we also present different approaches to determine service levels that best serve the business.

A. INVENTORY CLASSIFICATION MODELS

The equations and models used to describe inventory strategies and to determine stock and service levels use a large variety of inputs and variables. However, these models and equations differ from each other due to the characteristics of the items. There are characteristics such as warehousing similarities, holding cost, demand quantity during the year, and impact on the customer for any shortage.

For these reasons, it is necessary to create families or groups of materials. The purpose of this classification is to make distinctions in the models used for each group of materials. In this section, we discuss two known classification models: the Kraljic and the ABC models.

1. The Kraljic Matrix

The Kraljic model (Kraljic, 1983) model was introduced as a professional purchasing portfolio model. According to this model, a firm's supply strategy depends on two factors: profit impact and supply risk. This is important for managers because they can make different strategies and decisions taking into account the characteristics of each quadrant.

> The profit impact of a given supply item can be defined in terms of volume purchased, percentage of total purchase cost, or impact on product quality or business growth. Supply risk is assessed in terms of availability, number of suppliers, competitive demand, make-or-buy opportunities, and storage risks and substitutions possibilities. (Kraljic, 2008, p. 112)

Based on these two characteristics, the items are classified into four groups. Each group has its own characteristics, and thus requires different purchasing approaches and decision levels. The four groups are shown in Figure 1, and are positioned in the matrix according to the profit impact and supply risk.

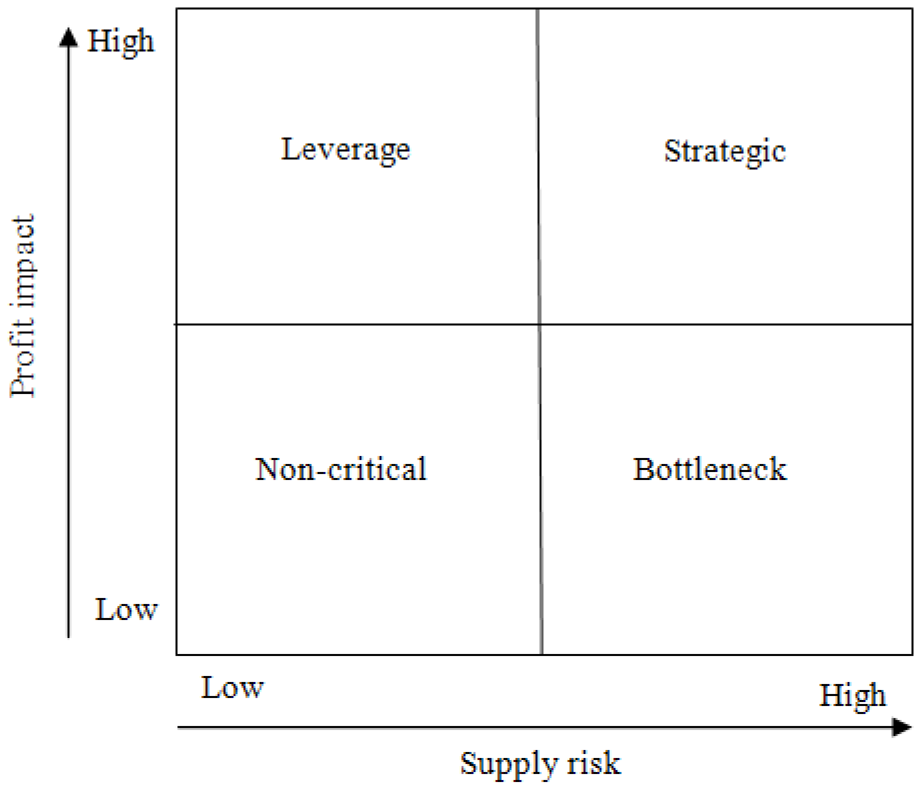

Figure 1. Kraljic Model (From Caniëls & Gelderman, 2005, p. 143).

Caniëls and Gelderman (2005), in their article about purchasing strategies using this matrix, go over each kind of material to make an analysis based on power and dependency. They give a brief description of each group, some examples of items, and the purchasing strategies that best fit in each quadrant.

Strategic Items are characterized by their high value for the corporation. They are located in the highest profit impact and highest supply risk. The reason for the supply risk is because of the lack of multiple suppliers; most of the time these items are fulfilled by a single source. The high impact on profit is due to the high cost of this kind of product (Caniëls & Gelderman, 2005). Some examples are propulsion and generation engines and gear boxes.

Bottleneck Items have an average impact on the corporation's profitability. Yet, the most common problem associated with them is due to the high risk of supply. This risk is associated with the dominant power position of the suppliers of this kind of material (Caniëls & Gelderman, 2005). An example is the sand used for the sandblasting process.

Leverage Items are distinguished by the ease with which they are obtained from multiple suppliers and their high costs. They are located in the top left quadrant; the supply risk is minimal and the influence on financial results is high (Caniëls & Gelderman, 2005). Some examples are the steel, pumps, and electronic equipment.

Finally, *Non-critical Items* have the lowest impact on the corporation. They are located in the quadrant with the lowest profit impact and the lowest supply risk. These items commonly have a low price per unit and a lot of suppliers that are easily found (Caniëls & Gelderman, 2005). Some examples of this kind of item are screws, bolts, pipes and electric articles.

However, we focus only on the characteristics of each group. Table 1 shows the main characteristics of the products, listed as dimensions, and how these characteristics are associated with different inventory factors. These factors are utilized in inventory strategies and stock and service level equations. Items from each of the categories can be measured on the same dimensions but will have different levels. For example, Bottleneck items would be low and Non-critical items would be high on the product Availability dimension. Another example is that Non-critical items would be low and Strategic items would be high on the Uniqueness of Suppliers' product dimension.

As shown in Table 1, each characteristic of the Kraljic model affects, either directly or indirectly the factors used in most of the inventory management and customer service models. These characteristics were derived from the most representative qualities that, according to Caniëls and Gelderman (2005), differentiate one type of good from another in the Kraljic model. We take these characteristics and associate each with equation variables. This association exists if the characteristic has any impact on a variable. For example, the Volume Purchased characteristic affects Holding Cost, which is a variable of the economic order quantity equation. This effect is due to the warehousing costs incurred when high volumes of inventory are purchased. Also, the higher the volume, the higher the cost, and thus the higher the opportunity cost.

Kraljic Model Materials Dimensions	**Impact of inventory and service level**
Volume purchased	Holding cost, Ordering cost
Percentage of total purchase cost	Holding cost
Impact on product quality	Lost demand cost, Profit margin
Impact on business growth	Lost demand cost, Profit margin, Demand
Availability	Lead time, Lost demand cost
Number of suppliers	Lead time, Ordering cost
Supplier’s capacity utilization	Lead time
Supplier’s break even stability	Lead time
Uniqueness of suppliers’ product	Ordering cost
Potential costs for non-delivery	Ordering cost, Lost demand cost
Potential costs for inadequate quality	Ordering cost, Lost demand cost
Competitive demand	Lead time
Make-or-buy opportunities	Holding cost, Ordering cost
Storage risks	Holding cost
Substitutions possibilities	Ordering cost, Lead time

Table 1. Effect of Kraljic Model Materials Dimensions.

These relationships between the Kraljic material characteristics and the model factors allow us to use this matrix to group the items for inventory management analysis. The reason is because each category has similarities within their items. For instance, non-critical items have low purchasing volume and are stored in low quantities; thus the holding cost is low.

In businesses with thousands or millions of specific materials, it is necessary to group materials in related families. This grouping is required in order to make decisions about strategies based on samples of each quadrant of materials. Purchase portfolios or inventory management strategies are included in these kinds of strategies for groups of materials.

Kraljic model is used in this project because it allows us to take samples from each quadrant. This ensures that the analysis is not biased and does not represent one quadrant more than the other. We also explain ABC classification model which classifies items based on different parameters. We use the ABC to classify the items in our sample because the different derivations of EOQ equations are related to this classification model.

2. ABC Classification Model

Many large businesses, such as manufacturing and repair companies, use millions of distinct items. The process of deciding how many items to order, or when to order, is not arbitrary. The first step of effective inventory management is classifying the items needed. One of the well-known classification models is called the ABC model. Some definitions and approaches need to be further explained before this model can be applied. This model, and the needed explanations, are all derived from Silver, Pyke, and Peterson (1998) in their book “Inventory Management and Production Planning and Scheduling.”

Stock-keeping unit (SKU) “will be defined as an item of stock that is completely specified as to function, style, size, color, and, usually, location” (Silver et al., 1998, p. 32). Because previous examination proved that about 20 percent of the SKUs account for 80 percent of the total annual dollar usage, inventories should not be controlled in a similar manner. Figure 2 shows an example of the Distribution by Value (DBV).

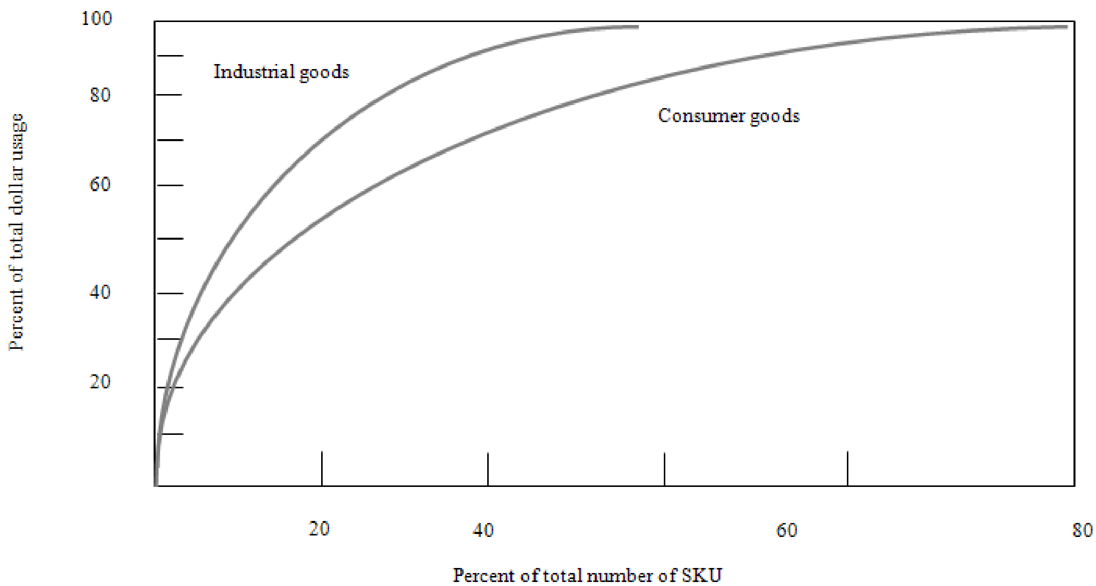

Figure 2. Distribution by Value of SKUs (From Silver et al., 1998, p. 33)

To develop a DBV curve, each SKU in inventory needs to be identified in the value of dollars per unit (v) and annual usage (demand) (D). Product Dv is then calculated for each SKU and sorted in descending order, starting with the largest values to the lowest. Then, plots on the graph should be made on the basis of the corresponding values of the cumulative percent of total number of SKUs. The aggregate effects of different inventory control policies can then be estimated (Silver et al., 1998).

Table 2 helps identify the SKUs that are most important. This table is most relevant for handling the diversity of disaggregate inventories.

> These SKUs will be assigned a higher priority in the allocation of management time and financial resources in any decision system we design. It is common to use three priority ratings: A (most important), B (intermediate in importance), and C (least important). The number of categories appropriate for a particular company depends on the circumstances and the degree to which it wishes to differentiate the amount of effort allocated to various groupings of SKUs. For example, one can always subdivide the Distribution by Value into further categories, such as (moderately important), as long as the resulting categories receive differentiated treatment. A minimum of three categories is almost always used, and we use this number to present the basic concepts involved. (Silver et al., 1998, p. 34)

Sequential Number	SKU I.D.	Cumulative Percent of SKU	Annual Usage Value (Dv)	Cumulative Usage	Cumulative Percent of Total Usage
1	-	0.5	$3,000	$3,000	13.3
2	-	1.0	2,600	5,600	24.9
3	-	1.5	2,300	7,900	35.1
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	22,498	-
199	-	99.5	2	22,500	100.0
200	-	100.0	0	22,500	100.0

Table 2. Sample Listing of SKUs by Descending Dollar Usage (From Silver et al. 1998, p. 34)

The Class A Items should receive the most personalized attention from management, then Class B, and finally Class C. Class A items account for 5-to-10 percent of total SKUs, but they account for roughly 50 percent or more of total annual value; therefore, they are the most important. Class B items account for 50 percent of total SKUs, and they account for most of the remaining 50 percent of the total value. Class C items make up the remaining SKUs that assume only a minor part of the value. Decision systems for Class C must be kept as simple as possible. Most companies keep a large number of units in stock for low value items to avoid the possible inconvenience of a stockout.

> For C items especially, and to a lesser degree for the others, as much grouping as possible of SKUs into control groups based on similar annual usage rates, common suppliers, similar seasonal patterns, same end users, common lead times, and so on, is desirable to reduce the total number of discrete decisions that must be processed. Each control group can be designed to operate using a single order rule and monitoring system. For example, if one SKU in the group requires an order because of low inventories, most of the other items will also be ordered at the same time to save on the cost of decision making. (Silver et al., 1998, p. 35)

The number of items in each class depends on how spread out the DBV is. The bigger the spread of the distribution, the more items will be in Class C, and so on. The ABC classification is often not done solely on the DBV curve. Sometimes decision makers opt to shift some SKUs from one class to the other, depending on what they assess is critical for the company's operation. Other times, they shift because it makes more sense from a demand rate and cubic-feet-per-unit perspective. It is necessary to point out that other literature suggests a two digit classification. One digit being based on value usage, as we have shown in the DBV curve, and the other based on customer demand or criticality (Silver et al., 1998).

The Inventory classification models explained above help to categorize items according to their importance for the corporation based on cost impact, frequency of use, and supply risk. Once we have those items classified in different families, it is necessary to apply inventory management models that fit according to the characteristics inherent to each group. The models that enable us to manage these items are discussed in the next section.

B. MANAGING ABC INVENTORIES

It was shown how to use the ABC model to classify certain items in inventories. It is even more important to know how to manage those items by calculating how much of an item to order, and when to place a replenishment order. Silver et al. (1998) explain several methods to determine this. These methods depend on the classification of the item being considered and a set of assumptions for each method. In the next sections, the basic models are explained for each of the categories of the ABC classification model, starting with Class B.

1. Class B Inventories

Some methods that will be explained in Class B will also be relevant for both Class A and Class C. This is why we start with it. Silver et al. (1998) show an equation to calculate the economic order quantity (EOQ). The EOQ is the amount of inventory needed to be ordered in the most cost-effective manner.

The equation is as follows:

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

where,

A = the fixed cost component in dollars.

D = the demand rate of an item, in units/unit time.

v = the unit variable cost of the item in $/unit.

r = "the carrying charge, the cost of having one dollar of item tied up in inventory for a unit-time interval (normally one year); that is, the dimensions are $/$/unit time." (Silver et al., 1998, p. 152)

Sometimes the number derived from this equation cannot be used. Examples include if the item ordered has a shelf life, a warranty expires, or if the storage has a limitation on capacity. Furthermore, the supplier may require a minimum amount of items to be ordered. The quantity then must be altered depending on these considerations (Silver et al., 1998).

This EOQ equation assumes that the demand rate is constant. However, if the demand rate is not constant, then D should be replaced by average demand accumulated over different periods.

To calculate the reorder point, which is when we should place the order, we use the following equation:

$$s = \bar{x}_L + k\sigma_{dLT}$$

where,

$\bar{x}_L$ = average forecasted demand during the lead time

$k\sigma_{dLT}$ = Safety stock

and,

k = safety factor (this will be discussed further in the service level section of the literature review.)

σ_{dLT} = standard deviation of demand forecasts and lead time, in units.

However, this equation assumes that both demand and lead times are normally distributed.

2. Class A Inventories

As discussed earlier, Class A inventories are the most important kind of inventories. There are fewer items in this class than the other classes, but items in Class A consume most of the dollars and/or demand. Some items are shifted to Class A from other classes because of other reasons that managers consider critical for the company.

According to Silver et al. (1998), there are guidelines for controlling type A items. These guidelines are as follows:

1. To use a manual rather than a computer system for records. Manual systems, like Kardex or VISI-Record, are good examples.
2. Frequent inventory reports should be shown to top management for careful inventory revision on a periodic basis.
3. Estimate and influence demand by:
    a. Providing input by forecasting manually. An example of this is getting an advance notice of your customer needs.
    b. Establishing predictability of demand. This can be done using various methods. For example, when demand is known or scheduled, there is no need to keep a stock of the item needed. On the other hand, when demand is not known, it sometimes makes sense to keep some stock of the items, even if it is expensive. It also makes sense to share some stock with different companies within the same industry on some items of high value and unknown demand.
    c. Changing the demand pattern by negotiation with customers, making efficient shipping decisions, and altering price structures, etc.
4. Estimate and influence supply by not only accepting the status quo, but by always negotiating with the supplier to reduce lead time and variability.
5. Be very conservative in stocking this class of items because overstocking can be very expensive.
6. Review order points and quantities frequently because changes might be of costly consequences.
7. Determine order quantities as precisely as possible, due to the importance of Class A items.

8. Estimate the cost of shortages in determining levels of safety stock, including the cost of emergency air shipments, of expediting from both in-house and out-of-house sources, and other actions.

Approaches for Class A items that have a high enough average demand in a lead time (more than 10 units) is discussed in the Class B inventories section because the same approach can be applied. However, if the average forecast demand in a lead time is below 10 items, then a discrete distribution, like the Poisson, should be used. This is because these types of items require a more accurate calculation. The remainder of this section is concerned with addressing the simultaneous determination of the safety factor and quantity for the faster movement of Class A items. (Silver et al., 1998).

In the next equations, it is assumed a shortage cost per unit short and a normal lead time demand. The equations are for an unknown quantity and safety factor. To calculate the correct quantity to order and safety factor for these types of items, the following equations should be used (Silver et al., 1998, p. 352):

$$Q = \sqrt{\frac{2AD + DB_2 v \sigma_L G_u(k)}{rv}}$$

and

$$p_u \geq (k) = \frac{Qr}{DB_2}$$

where,

A = fixed cost component incurred with each replenishment

D = annual demand

B_2 = fixed cost fraction per unit short

v = unit price

σ_L = standard deviation of lead time demand

G_u= a function of the unit normal variable

k = safety factor

$p_u \geq (k)$ = a function of the unit normal variable (1 – service level)

r = carrying cost

Q = order quantity

To calculate the reorder point(s):

$$s = \bar{x}_L + k\sigma_L$$

This reorder point equation does not differ from the method shown in the Class B section.

3. Class C Inventories

Silver et al. (1998) note that Class C items represent a large portion of the inventory, but only consume a low value of the inventory in the company. However, it is always important to keep in mind that even low value items can have severe shortage consequences associated with Class C items. One example is that a shortage in Item 1 can cause delay in the usage of Item 2, because it is dependent on Item 1. This may affect future dealings with this customer. If this customer was important, the effect on the company could be even bigger. Another example is that even when an item is low in dollar value, it still may hold a sentimental value for the customer's president. These items could then have a high implicit cost associated with a shortage.

It is important to establish principles for Class C items that keep control costs as low as possible. It is not too much of an investment to try to control Class C items when their value is very low compared to items in other classes of inventory. This can be achieved by keeping labor and paperwork to a minimum. Reliance on electronic equipment for most of the control costs and data capturing is recommended. Records for Class C items should be kept in the least expensive way; manually or electronically (Silver et al., 1998). We should note that the classification of an item as Class C should always be open to revision. This avoids the downgrading of important items to a Class C status (Silver et al., 1998).

To calculate the reorder quantity and reorder point for Class C items, the same equations shown in the Class B section should be applied.

The factors used in the equations above can be found in the historical data of the company; however, a service level, which is also included in the equations, must be either assigned arbitrarily or calculated. In the next section, we show some possible approaches to calculating it.

C. CUSTOMER SERVICE

There are many definitions of customer service. However, all of them agree when it comes to the goal of customer service. The goal is the fulfillment of customer needs using the tools available in the best way. There is a definition for customer service from the International Customer Service Association. Rinehart, Cooper, and Wagenheim (1989) define "customer service as those functions within a business that have customer satisfaction as their responsibility and provide that satisfaction through the fulfillment of sales order demand and/or information needs" (p. 64).

Customer service levels could be defined as the percentage of orders, which customers receive on time. This percentage is fundamental for the determination of safety stock levels. This determination is going to provide satisfaction to the customer and is considered a success factor.

There are some problems that arise with the definition of *service level*, specifically, with the setting of a perfect, feasible, and cost-effective percentage. Another problem is the identification of the inventory required to obtain the service level we are seeking.

According to Ettl, Feigin, Lin, and Yao (2000), it is difficult for asset managers to calculate and decide about the trade-off between the service levels the company wants to offer its customers, and the investments the company requires on inventory, in order to attain the service levels expected.

In the next two sections, we explain two existing approaches to the calculation of service levels we found. One approach focuses on how to assign a service level target, and the other provides a way to determine a cost-effective customer service level. We analyze these approaches in order to determine which best suits our project.

1. The Service Level Target

There are common mistakes in the process of setting perfect service levels. In some companies, the service level used to calculate optimal stock levels is given arbitrarily. Sometimes it is based on past management experience, intuition, or it is based on agreed goals with customers.

Coleman (2000), in a journal article about how to determine the correct stock level, provides a four step procedure to determine it. He takes into account relevant information and some of the most important factors in safety stocks.

In the first step, Coleman (2000) calculates the optimal number of stockouts, which is given by the holding cost per unit and the shortage cost per unit. However, one important assumption is that the shortage costs are identified. The equation is as follows:

$$\text{Optimal Number of Stockouts} = \frac{\text{Holding Cost per Unit per Year}}{\text{Shortage Cost per Unit}}$$

The second step given by Coleman (2000) is to calculate the number of cycles each year, which is given by the average annual demand and the order Quantity. The relationship between these two variables, in addition to the number of orders cycles, indicates the number of resupply lead times for a year. However, this equation assumes that there is certain regularity or frequency in the replenishment cycle. The third step is to calculate the ratio between the equations of step one and two. The equations are as follows:

$$\text{Number of cycles per year} = \frac{\text{Average Annual Demand}}{\text{Order Quantity}}$$

$$\text{Probability of stocking out during each order cycle} = \frac{\text{Optimal Number of Stockout Occasions Each Year}}{\text{Number of Exposures to Stockout Each Year}}$$

Since the third step is the probability of stocking out during each lead time, the service level, which is the opposite, is calculated as:

$$\text{Service Level} = 1 - \frac{\text{Optimal Number of Stockout Occasions Each Year}}{\text{Number of Exposures to Stockout Each Year}}$$

The combinations of all these equations yield a single one. This equation contains the variables not only to calculate it, but, to analyze how the change on any of the factors would affect the service level. According to Coleman (2000), it is also useful to calculate the shortage cost for a given arbitrary service level. If the shortage is unknown (which is an important assumption in Equation 1), managers can use the equation backwards to determine if the resulting shortage cost is logical.

The final equation, according to Coleman, is as follows:

$$\text{Service Level} = 1 - \frac{\text{(Holding Cost per Unit per Year) (Order Quantity)}}{\text{(Shortage Cost per Unit) (Average Annual Demand)}}$$

In addition, these variables are to be revised depending on the type of material, type of business, and the characteristics of the supply chain parties involved. These characteristics are to be based on the selected classification model.

2. Cost-Effective Customer Service Level

Jeffery, Butler, and Malone (2008), in a research paper about how to determine a cost-effective customer service level, identify different variables that can be used to determine equations for customer service levels and the cost associated with achieving it.

In order to determine the customer service level, Jeffery et al. work on two classes of logistic regression models. These models allow a binary dependent variable that indicates if an order was late or on time. One class is the planning model that quantifies the historical relationship between inventory and delivery performance, which is service level. The other class is the insight models that are developed to analyze the effects of different factors such as lead time, demand variability, and forecast error on the product group performance. It is necessary to analyze these factors because they have an important impact on customer service, and the changes they create can be determined. It is also important because it will enable organizations to analyze the benefits of focusing efforts on certain improvements.

Because of the relationship between inventory level and the demand forecast, Jeffery et al. (2008) work with an independent variable called "weeks of inventory." This is calculated (along with the three insight models), using the following equations:

$$\text{Weeks of Inventory (WOI)} = \frac{\text{Inventory on hand}}{\text{Demand forecast per week}}$$

$$\text{Forecast error} = \text{absolute}\left(\frac{\text{Forecast demand} - \text{Actual demand}}{\text{Actual demand}} \right)$$

$$\text{Order lead time} = \text{Requested delivery time} - \text{Order placed date}$$

$$\text{Coefficient of variation of demand} = \frac{\sigma \text{ of demand for product i}}{\mu \text{ of demand for product i}}$$

Subsequent to the equations above, Jeffery et al. (2008) developed an equation to calculate the cost of providing a certain service level according to the inventory level needed for each given one. The cost equation includes holding costs such as warehousing, obsolescence, scrap, and opportunity costs. It also includes a lost sales cost, which is obtained using a survey with customers. In this particular case, they indicated a twenty percent likelihood to move to other suppliers if a product is not delivered on time.

Of course, this percentage of migration to other companies is the result of a particular case analyzed by Jeffery and the other authors in their research paper. However, this portion of lost sales must be restated in the analysis of this project. The reason for this restatement is that there is no option for the customers in the shipyard to migrate (for a single product) to other suppliers, due to the availability of global services. This situation only happens in a few situations for large equipment or very expensive items that are only required in very limited quantities.

The equation for the cost of service level, according to Jeffery *et al*., is given as follows:

Cost of service level = Inventory units per period*Inventory Holding Cost per unit
+ expected lost sales units per period * profit margin per unit

Similarly, the holding cost is a function of the Weeks of Inventory, the forecast, and the different costs incurred with the inventory.

Finally, the optimal cost-effective customer service level is found by plotting the points of cost and service level for each week of inventory. The optimal service level is selected according to the lowest cost. As an example, Figure 3 shows a relationship between inventory, customer service level, and cost for a give product—to which effective customer is achieved with 3.6 weeks of inventory.

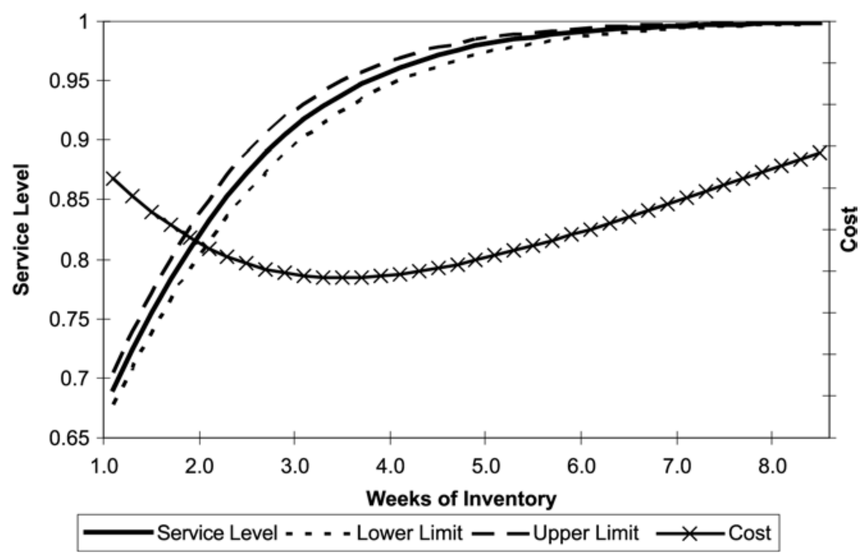

Figure 3. Example of Relationship between Inventory, Cost and Customer Service Level (From Jeffery et al., 2008, p. 230).

D. SUMMARY

The overall procedures needed to implement inventory strategies were covered in this chapter. First, we described the Kraljic and the ABC classification models used to group the different kind of items in our inventory. The Kraljic model classifies the items based on cost impact and supply risk. We use Kraljic model to select small sample of items for detailed study. ABC model classifies the items based on cost impact and usage frequency. Then, we explained inventory management models and the equations used in each one. For each class of the ABC model, we assign the adequate equation to be used. As mentioned above, most of the data needed to apply this model is available—except the data for service level.

To avoid assigning an arbitrarily service level, we showed two methods to determine service level. One shows the way to assign a service level and the other shows how to determine a cost-effective customer service level. These methods give an accurate service level based on the cost assessment due to stockout risks. The second approach uses the expected lost sales during the period as a variable to determine the service level. Because lost sales are not applicable to the inventory we study, we decided to use the first approach explained in this section.

In the next chapter, we apply the procedures explained in this chapter to the data collected from COTECMAR to develop the best inventory strategies. For the classification of the items, the models are applied as explained.

II. DATA COLLECTION

This chapter covers the selection of items and their classification. This data is collected from COTECMAR's ERP. First, the selection of an adequate sample of items is covered. This selection is made from an existing classification in the corporation database on the criticality of the items (Kraljic model) by Diaz and Leaño (2009). Then, the selected items are organized according to the ABC classification model and listed in a stock-keeping unit table by descending value. This classification allows us to apply models to each class in a subsequent section.

A. SELECTION OF THE ITEMS

As a starting point, we take a COTECMAR research report (Diaz & Leaño, 2009) in which the authors classify goods and services according to the Kraljic model. The Kraljic model is used primarily to determine purchasing strategies and portfolios. Although this classification was made in order to classify the vendors and suppliers of the corporation, it is useful because the items are classified according to some similarities in their characteristics. As discussed above, these characteristics affect directly or indirectly the parameters and variables we use for inventory management calculations.

The Goods Supply Matrices (Figures 4 and 5) show the classification of goods by family[2] according to their impact in cost and supply risk. Most of the items are classified the same way, whether they are used for repair or shipbuilding activities. However, there are a few differences in the classification of some family items due to their nature of use. For example, steel is needed in large quantities in shipbuilding for the production of the complete hull of a given vessel; in contrast, for repair purposes, steel is seldom needed, and then, only in small quantities. The classifications are shown in Figures 4 and 5.

[2] Family here refers to a category of items. For example, the Pipes family includes several different sizes, lengths, and materials (cooper, steel, plastic) of pipes.

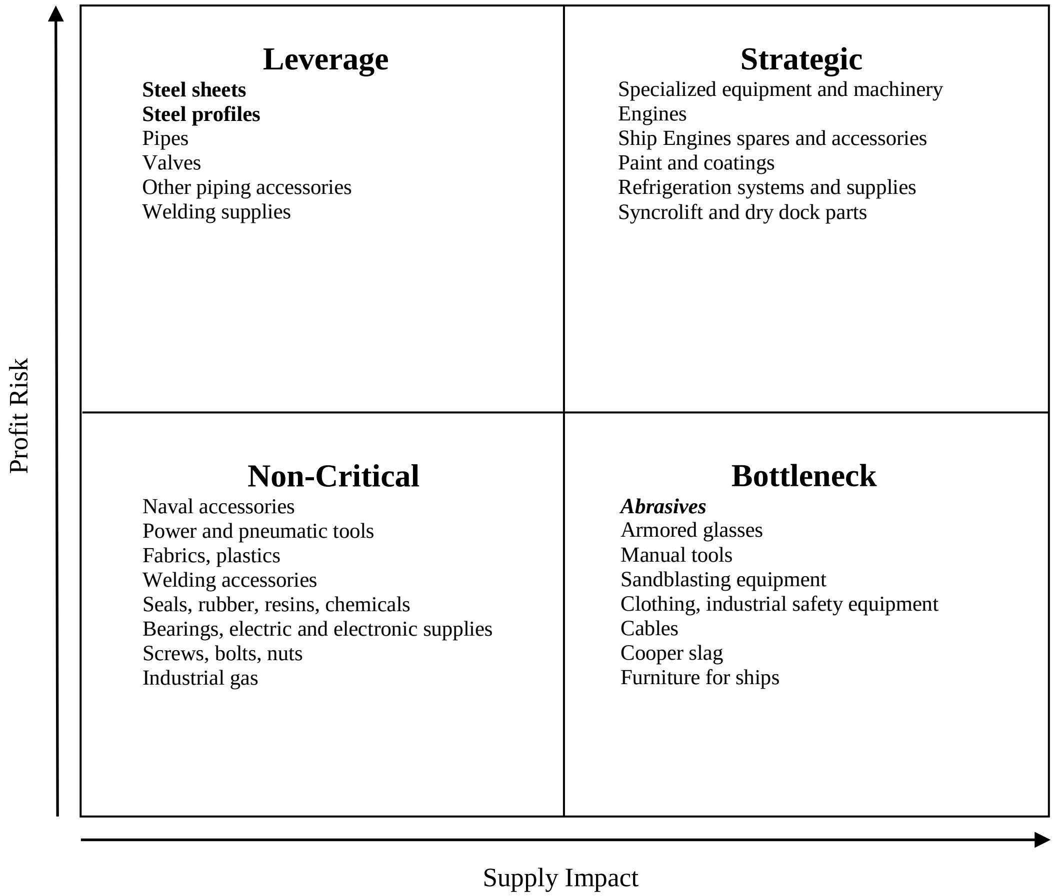

Figure 4. Goods Supply Matrix for Repairing and Maintenance (From Diaz & Leaño 2009, pp.42–43, after translation)

Figure 4 shows the item families in each quadrant for repair and maintenance activities. These activities are offered by the plants for both Navy fleet and civilian customers. In each family there are a large number of items, and each item has many different sizes, colors, shapes, weights, references, lengths, measures, and so forth—for each of the thousands of items used in several kinds of vessels.

The classification used for items related to shipbuilding is similar, with some differences, as shown in Figure 5.

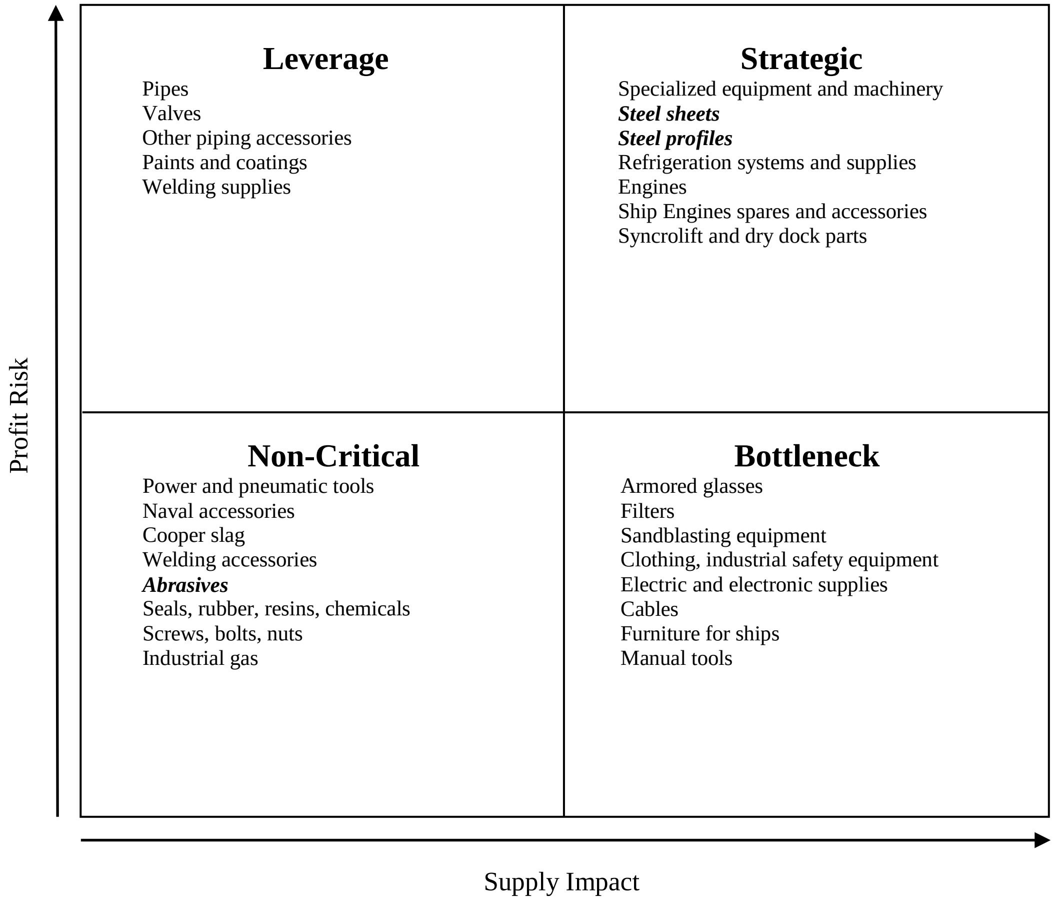

Figure 5. Goods Supply Matrix for Shipbuilding (From Diaz & Leaño 2009, pp.43–44, after translation)

From these groups of families, it is necessary to take a sample to run the models. As mentioned above, COTECMAR has three basic business lines or divisions: Bocagrande repair plant (Bocagrande), Mamonal repair plant (Mamonal), and Shipbuilding. Therefore, we take three items from each quadrant per business line, for a total of twelve items per business line, and a sum total of thirty-six items.

However, we cannot randomly choose these items because we may choose a very sporadic item. A sporadic item is not going to provide enough data to accurately analyze, and would therefore be completely useless. Consequently, it is necessary to select the items with regard to their usage. The items with a high usage volume are identified for each quadrant, and described accordingly in Table 3.

Bottleneck Items			
Line	**Item Family**	**Code**	**Item**
Mamonal	Clothing and Industrial Safety Eq.	20324674	DIELECTRIC SAFETY BOOTS - SIZE 41
	Cables	20006167	RUBBER WRAPPED CABLE 3 X 12 110V
	Cooper slag	20473778	MINERAL COOPER SLAG GRANULOMETRY GR-3
Bocagrande	Clothing and Industrial Safety Eq.	20324674	DIELECTRIC SAFETY BOOTS - SIZE 41
	Cables	20006167	RUBBER WRAPPED CABLE 3 X 12 110V
	Cooper slag	20473778	MINERAL COOPER SLAG GRANULOMETRY GR-3
Shipbuilding	Armored glasses	20259556	POLYCARBONATE ARMORED GLASS LEVEL 3 LEFT 46X69X 700mm
	Clothing and Industrial Safety Eq.	20324667	DIELECTRIC SAFETY BOOTS - SIZE 40
	Electric-electronic Supplies	20008420	NON-CONDUCTING TAPE SUPER 33+ 19MM X 20MTS

Non-Critical Items			
Line	**Item Family**	**Code**	**Item**
Mamonal	Naval accessories	20145873	SUPERBRAIDED NYLON ROPE 1.1/2"
	Welding accessories	20019969	STONE FOR FRICTION LIGHTER
	Industrial gas	20041076	AGA SOL
Bocagrande	Naval accessories	20401665	FLUORESCENT LAMP IP67 2X18W 120VAC 60HZ REF. 1044216205
	Bearings	20023188	BEARING REF. 6205 ZZ C3
	Screws	20028060	SCREW HEX GALVANIZED UNC 5/8" X 2.1/2"
Shipbuilding	Naval accessories	20050498	NYLON ROPE 3/4"
	Screws	20055165	SCREW HEX STAINLESS AISI 304 UNC 3/8" X 1"
	Resins	20110017	WHITE GELCOAT 888

Table 3. Items Sample Selected per Quadrant per Business Line

Strategic Items			
Line	**Item Family**	**Code**	**Item**
Mamonal	Paints	20085926	ADJUSTER FOR EPOXY PAINT REF. 121135
	Paints	20036409	CATALYST FOR POLY EPOX REF. 9800 (13227)
	Pains	20021320	ANTICORROSIVE POLY EPOX RED REF. 9101 (210050)
Bocagrande	Paints	20007560	CATALYST FOR POLY EPOX REF. 9800 (13227)
	Paints	20020118	POLI EPOX GREY REF. 9600 (213222)
	Refrigeration systems and supplies	20038557	FREON 22
Shipbuilding	Steel (sheets and profiles)	20001513	ANGLE C/S 1/4" X 2"
	Steel (sheets and profiles)	20020545	PLATE C/S ASTM A-36 1/4" X 2"
	Steel (sheets and profiles)	20057909	GALVANIZED SHEET ASTM A-366 GAUGE 20 X 4' X 8' (1.22MTx2.44MT)

Leverage Items			
Line	**Item Family**	**Code**	**Item**
Mamonal	Steel (sheets and profiles)	20269746	NAVAL STEEL SHEET ASTM A-131 3/8" X 8' X 20' (WEIGHT: 1113.0KG)
	Pipes	20068257	FLANGE SLIP ON 6" 150 LB C/S ASTM A105 RF
	Welding accessories	20183202	WELDING AWS E7018 1/8"
Bocagrande	Steel (sheets and profiles)	20001513	ANGLE C/S 1/4" X 2"
	Pipes	20029098	PIPE C/S 1" SCH 40 SEAMLESS
	Welding accessories	20183271	WELDING AWS E7018 3/32"
Shipbuilding	Pipes	20029098	PIPE C/S 1" SCH 40 SEAMLESS
	Paints	20085926	ADJUSTER FOR EPOXY PAINT REF. 121135
	Welding accessories	20183295	WELDING AWS E7018 5/32"

Table 3 (continued). Items Sample Selected per Quadrant per Business Line

In order to get the data we need for calculation purposes, we downloaded several files from the ERP software. Infor XA is the maker of the ERP system used by COTECMAR. In this software, COTECMAR employees enter the data in order to make transactions according to each division or department. For instance, the Human

Resources Department enters data related to wages, primes, labor, etc. The Production Department enters data such as working hours, and they also do their material requisitions through the system. The Purchasing division does Purchase orders in the system. The Warehouse Division performs all material movements and transactions in the system. Accounting does the billing, cost, and all of the accounting transactions in the system. Thus, we can rely on this software to download the data we need, according to the information we want. The source of the specific data used is detailed for each equation or analysis performed.

In the previous section, the items have been selected from the Kraljic model in use at COTECMAR, taking into account items with substantial information that will allow us to perform a good analysis. In the next section, these selected items are classified according to the ABC model and listed in a stock-keeping unit table in descending value.

B. DATA GATHERING

In order to analyze our sample we need to gather various data. The total number of items for data gathering and analysis is 35. The sample was 36 items, but the item ADJUSTER FOR EPOXY PAINT REF. 121135 for Mamonal and Shipbuilding has the same warehouse location so they are treated as a single item instead of two items. Some of the other items are also the same in Mamonal and in Bocagrande, but they have different inventory locations, and this characteristic makes them different SKUs. For simplicity, and because Mamonal and Shipbuilding are co-located, demand for Mamonal and shipbuilding will be treated the same.

In the SKU table, the cumulative percentage is calculated by adding the percentage of each SKU. The percentage for each SKU is calculated by dividing 100% by the total of SKUs, which is a total of about 2.86% per SKU.

For the calculation of the Annual Usage we need two values: the Annual Demand and the Unit Price. For the Annual Demand, we compare the information in three files downloaded from the ERP System. We have information from January 2006 to January 2012, although some files only contain information from January 2008 to January 2012.

The first file is the Requisition record, where we have the following information for each transaction: requisition number, class or family of material, code of the item, name of the item, quantity, unit of measurement (i.e., units, pounds, gallons), name of the project, cost center, requisition date, and date required. Extra information from the system, due to the correlation with the transactions from other divisions and departments, is unnecessary.

The second file is the Purchase Orders (PO) record. Here, we have PO number, item codes, item name, warehouse the item goes, unit of measurement, quantity, unit price, total price, PO date, delivery date, and supplier name. As before, the extra, unnecessary information is ignored.

Finally, the third file is the Warehouse (WH) Transactions records. In this file, we have the quantity, the transaction (entrance, delivery, return, entrance from consignment, transfer), item code, warehouse (Bocagrande, Mamonal), item name, unit cost, date, and balance quantity. Extra unnecessary information is also ignored here.

For the analysis, we leverage the data collected from the first file—the Requisition Record—and we get the average demand quantity per year from 2008 to 2011[3]. We do the same with the PO record from 2006 to 2011, and the same with the WH transactions record from 2008 to 2011, and we come with an average with high variation. The reason for this high variation might be the variation in the type of projects and the different technologies used in the steel works.

For the price calculation, we take two averages: the average price from the PO Records file over the years and the average from the WH transactions file. We obtain a similar price number with small variation between one file and the other.

The remaining information in the table is the cumulative usage and the cumulative percentage of the total usage, which is simple to calculate once we complete the annual usage column and we order the items in descending value.

[3] In all cases 2012 data is ignored in order to compare complete annual data.

The first item in the list of the sample is “AGA SOL,” which is the commercial name of an industrial gas used to cut steel. First, we take the average unit price per year of that specific item from the Purchase Order data file. Then, we average out all the values for all the years from 2006-2011. From the Warehouse Transaction data file, we take the exact the same information of unit price per year from 2008-2011. Here, we find that the average unit price from the purchase order data file is COP[4] 2,020.21. From the Warehouse Transaction data file, the average unit price is COP 2,017.84. These numbers are close, and so we can keep them to analyze the other items. Table 4 shows the calculation for AGASOL unit prices.

AGASOL UNIT PRICE		
Year	**P.O. Data Unit Price (COP)**	**WH Transactions Data Unit Price (COP)**
2006	1,796.46	-
2007	1,866.93	-
2008	2,022.26	2,002.62
2009	2,000.00	1,999.90
2010	2,000.00	2,000.00
2011	2,058.57	2,068.87
Average	**2,020.21**	**2,017.84**

Table 4. AGASOL Unit Price Calculation

The purchase order data is an accurate number because it is taken by actual market transactions. It gives us the average price the suppliers are selling these items. The warehouse transaction data is also an accurate number because it gives us the unit-averaged price regardless of the variation of the unit price when purchased. Therefore, we keep both numbers to analyze the unit price of all items. However, we are going to dismiss the data from 2006 and 2007 because the warehouse data is not available for those years. This also has a positive impact on our analysis because it makes our data more recent and reduces the variation of cost due to inflation.

[4] COP, Colombian Pesos

The second step is to calculate the demand. For this, we take the Requisition data file and add all of the quantities for each year. Then, we average out the totals of each year. We follow the same process with the purchase order data file. Finally, we do the same with the Warehouse Transaction data file.

In the Warehouse data file, there are multiple kinds of transactions, as follows:

RW - Entrance from Transfer
IW - Exit from Transfer
IU - Exit to Project
IS - Exit for OH or Investment
RC - Entrance from Consignment
RS - Return from Project
VR - Return for PO
RP - Entrance from PO

For the purpose of collecting demand data, we only use IU and IS transactions. From this quantity, we subtract the quantity of RS transactions. The ERP has 44 virtual warehouses. Some of them are created for specific projects and other are created for suppliers consignments. Thus, we need to select an adequate set of virtual warehouses that belong to one of the two sets of physical warehouses located at either Mamonal or Bocagrande (Table 6 shows all warehouses). After selecting this data, we add all the quantities for each year. Then we average out the totals of each year, just as we did with the Requisition and Purchase Order files. One example of this calculation is shown in Table 5.

AGASOL DEMAND (MAMONAL)					
Year	**Requisition Data Demand**	**P.O. Data Demand**	**WH Trans. Deliveries**	**Returns to WH**	**Final WH Trans. Data Demand**
2006		80,169.00			
2007		26,196.00			
2008	33,678.70	9,396.00	28,139.50	151.50	27,988.00
2009	99,856.26	44,938.50	39,580.00	1,324.50	38,255.50
2010	117,350.30	64,627.00	31,244.00	809.50	30,434.50
2011	100,654.20	69,605.00	29,091.00	1,341.50	27,749.50
Total	**87,884.87**	**49,155.25**			**31,106.88**

Table 5. AGASOL Demand Calculation in Kilograms

As shown in Table 5, average demand per year is very different amongst the date files. The requisition demand is high because it contains requisitions made from the warehouse division to the purchase division, as well as requisitions made from the production department to the warehouse division. Another reason might be that the production department inflates their actual needs in order to make sure that plenty of raw materials are available for their use. The purchase order demand is high because it contains all items purchased for use and for stock. Consequently, the demand from the Warehouse Transaction data files is more accurate because it gives the actual quantities delivered to production. Therefore, for all the remaining items, we are only going to use the Warehouse Transaction data files.

Warehouse	Description	Physical Location
ACT	Fixed Assets Warehouse (PPE)	Mamonal
FCU	Virtual Warehouse Frigates (Custody)	Bocagrande
FRG	Virtual Warehouse Frigates	Bocagrande
MBY	Manta Bay Project (Mamonal Km9)	Mamonal
MLG	Virtual Warehouse Malaga	Bocagrande
OPV	Virtual Warehouse OPV	Mamonal
PAF	Light Patrol Project	Mamonal
PTC	Shipbuilding Warehouse (Mamonal Km9)*	Mamonal
PTM	Warehouse Mamonal Plant*	Mamonal
PV2	Warehouse OPV 2*	Mamonal
P01	Production*	Mamonal
S01	Services Mamonal*	Mamonal
S02	Services Bocagrande*	Bocagrande
S03	Services Shipbuilding*	Mamonal
S04	Services Holding*	Mamonal
1	Mamonal	Mamonal
2	Bocagrande	Bocagrande
3	Armored Project Bogota	Mamonal
4	Distribuidora Ancla**	Mamonal
5	Distribuidora Ancla Bocagrande**	Bocagrande
6	Empaquetaduras Y Empaques Bocagrande**	Bocagrande
7	Disprotec – Bocagrande**	Bocagrande
8	Disprotec- Mamonal**	Mamonal
9	Central De Soldaduras Mamonal**	Mamonal
10	Central De Soldaduras Bocagrande**	Bocagrande
11	Propulsora Mamonal**	Mamonal
12	Agafano Bocagrande**	Bocagrande
13	Propulsora Bocagrande**	Bocagrande
14	Soldarco**	Mamonal
15	Tatis Y Cia**	Mamonal
16	Pintuco S. A.**	Mamonal
17	Pintuco Bocagrande**	Bocagrande
19	Central De Soldaduras Mamonal**	Mamonal
22	Agafano Mamonal**	Mamonal
23	Cryogas**	Mamonal

24	S. P. Y S. Mamonal**	Mamonal
26	Tuvacol S. A.**	Mamonal
27	Central De Mangueras**	Mamonal
28	Sinco Ltda Mamonal**	Mamonal
29	Sinco Ltda Bocagrande**	Bocagrande
30	Central De Soldaduras Bocagrande**	Bocagrande
32	Empaquetaduras Y Empaques**	Mamonal
33	S. P. Y S. Bocagrande**	Bocagrande
36	Tuvacol Bocagrande**	Bocagrande

*Created on January 1st 2012

**Created with Suppliers Names due to Consignment Inventory (Vendor-Managed Inventory)

Table 6. COTECMAR Warehouses

C. ITEM CLASIFICATION

With the demand and value information, we are ready to calculate the annual usage from the demand and purchase cost, and then classify the SKUs according to the ABC model. This information is presented in Table 7 and organized in descending value. Then, cumulative usage and the cumulative percentage of the total usage are also shown.

No.	SKU NAME	Cum. Percent SKU	Annual Usage (Dv) (COP)	Cumulative Usage (COP)	Cumulative Percentage of total usage	Item Class
1	NAVAL STEEL SHEET	3%	496,116,781	496,116,781	31%	A
2	FLUORESCENT LAMP	6%	156,299,811	652,416,591	41%	A
3	WELDING 1/8"	9%	123,649,347	776,065,939	49%	A
4	ANTICORROSIVE EPOX	11%	108,374,385	884,440,324	56%	A
5	MINERAL COPPER SLAG	14%	91,134,607	975,574,931	61%	B
6	ADJUSTER FOR EPOXY	17%	81,797,032	1,057,371,963	66%	B
7	MINERAL COPPER SLAG	20%	72,559,112	1,129,931,075	71%	B
8	CATALYST FOR EPOX	23%	72,078,714	1,202,009,789	76%	B
9	WELDING 5/32"	26%	70,282,098	1,272,291,886	80%	B
10	AGA SOL	29%	62,805,626	1,335,097,513	84%	B
11	CATALYST FOR EPOX	31%	50,937,762	1,386,035,274	87%	B
12	POLY EPOX GREY	34%	31,399,074	1,417,434,348	89%	B
13	SAFETY BOOTS SIZE 40	37%	19,573,832	1,437,008,180	90%	B
14	ANGLE C/S 1/4" X 2"	40%	18,103,281	1,455,111,462	91%	B
15	WHITE GELCOAT	43%	15,552,737	1,470,664,199	92%	B
16	SAFETY BOOTS SIZE 41	46%	15,145,864	1,485,810,063	93%	B
17	ANGLE C/S 1/4" X 2"	49%	14,811,776	1,500,621,839	94%	B
18	FLANGE SLIP ON 6"	51%	11,320,631	1,511,942,470	95%	B
19	SUPER NYLON ROPE	54%	9,525,719	1,521,468,189	96%	B
20	GALVANIZED STEEL SHEET	57%	9,367,134	1,530,835,323	96%	B
21	WELDING 3/32"	60%	8,679,333	1,539,514,656	97%	B
22	SAFETY BOOTS SIZE 41	63%	7,457,074	1,546,971,730	97%	C
23	NON-CONDUCTING TAPE	66%	6,545,589	1,553,517,319	98%	C

24	FREON 22	69%	6,296,730	1,559,814,049	98%	C
25	PLATE C/S 1/4" X 2"	71%	5,627,581	1,565,441,630	98%	C
26	PIPE C/S 1" SEAMLESS	74%	5,487,622	1,570,929,253	99%	C
27	SCREW HEX GALVANIZED	77%	5,162,920	1,576,092,172	99%	C
28	CABLE	80%	5,145,051	1,581,237,223	99%	C
29	PIPE C/S 1" SEAMLESS	83%	4,792,233	1,586,029,456	100%	C
30	ARMORED GLASS	86%	1,724,951	1,587,754,407	100%	C
31	CABLE	89%	1,661,624	1,589,416,031	100%	C
32	SCREW HEX STAINLESS	91%	739,490	1,590,155,521	100%	C
33	NYLON ROPE 3/4"	94%	425,544	1,590,581,065	100%	C
34	STONE FOR FRICTION	97%	334,938	1,590,916,003	100%	C
35	BEARING	100%	306,642	1,591,222,645	100%	C

Table 7. Listing of Sample SKUs by Descending COP Usage

Figure 6 shows the distribution of SKUs by value. This figure is based on the values from Table 7. We can see from this figure—and the table—that the figure follows the regular distribution for industrial goods, of which about 26% of the SKU account for about 80% of the total annual COP usage. Thus, not all of the inventory should be controlled to the same extent. This is why we use the ABC classification model, as suggested by Silver et al. (1998).

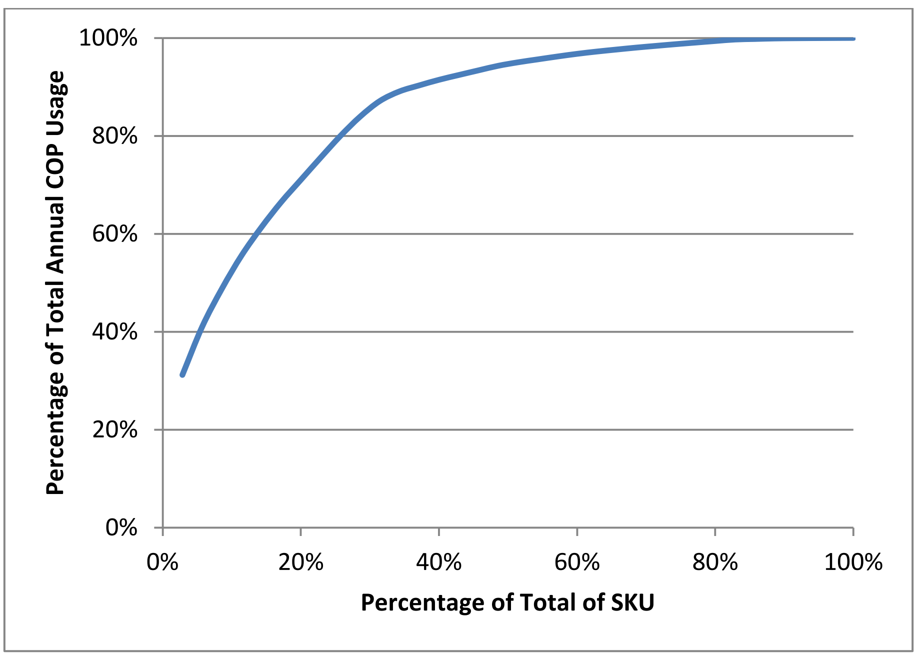

Figure 6. Distribution of SKUs by value

With Table 7, we can classify inventories based on importance. The most important inventories (rated A) are located in positions 1 to 4, because they represent about 11% of the total SKU and account for about 56% of the total annual COP value. The second most important items (in relation to Class A items) are Class B items, which are located in positions 5 to 21. These B items represent about 49% of the total SKU and account for 41% COP usage, which is most of the remaining annual COP usage. Finally, the least important are Class C items, because they represent a very small part of the total COP investment. The Class C items are located in positions 22 to 35. These items represent about 40% of the total SKU and account for only 3% of the total COP usage.

In the previous sections, we have selected the items based on the Kraljic model from existing research made in COTECMAR. The items are selected by taking into account those that have enough good information to apply the models, and thus make valid inferences about the whole category of items. Furthermore, the selected items have been classified according to the ABC classification model, and are listed in a SKU table in descending value. From this table, we take the items A, B, and C, according to the percentage of dollar usage and the cumulative percentage of SKUs.

In the next chapter, we discuss inventory strategy models for each class of items, and determine the variables needed for each equation. For the inventory management models, assumptions and rules are addressed. For the service level calculation, the correct service level is determined in order to maintain a level that satisfies customer needs based on stockout costs.

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IV. INVENTORY ANALYSIS

This chapter covers the determination of the variables that will be needed for inventory management calculations. Moreover, this chapter includes discussion of different inventory models, along with the assumptions related to each one and the selection of the appropriate model. Furthermore, this chapter goes over the application of the data in all of the equations. Finally, at the end of this chapter, all of the findings are listed. In the following chapter, working from these calculations and findings, we present conclusions and recommendations.

A. DEMAND RELATED ANALYSIS

In this section, we determine the variables to be used in the equations and explain how each one is calculated using the existing data.

1. Demand

In this section, we explain the big picture and demand patterns—the behavior of the demand—in COTECMAR. We also determine what kind of data or information related to the demand is useful for the purpose of our research scope. COTECMAR's projects—shipbuilding, overhauling, and repairing—have an important impact upon the behavior of the demand. With these kinds of projects, the demand for items is at times sporadic and at other times regular. These characteristics belong to both dependent demand items and independent demand items. Therefore, we first define dependent demand items and the process to manage them. Then, we turn to our research focus to the definition of independent demand items and the process to manage them. Finally, we explain the calculation of demand for items that have independent demand, in order to use it in the equations for this project.

According to the big picture of the calculated demand in the "Organization of the Items" section for the SKU table, we find that some of the items have abnormal variation—different from regular variability, seasonality, or normal patterns. Some items have annual demands that are fairly constant. Other items have very high variability. Items with high variability either show no particular pattern, or have a pattern that increases over time.

We attribute abnormal variation to specific projects that have a dependent demand and go over a predetermined span of time. For example, when COTECMAR receives an order to build a new ship, the demand for steel sharply increases in the first phase of the shipbuilding process. This is because the complete hull is built in the first phase. When the hull is completed, the demand for steel returns to its normal position. However, the demand for pipes, in the second phase, sharply increases during the outfitting process. Again, the demand for pipes goes back to its normal position after this phase is completed, and so on for all of the items that are going to be used for that specific shipbuilding project. For this kind of item, different approaches from the regular EOQ and ROP models are applied. According to Silver et al. (1998), materials requirement planning (MRP) is an approach to manage this kind of demand. The MRP approach is explained in the dependent demand items section below.

Based on the characteristics of the demand we observe in the data, we consider it necessary to determine whether the demand belongs to dependent demand items or to independent demand items. The literature review does not cover this classification method, but it is necessary to determine this because, depending on this classification, either the inventory models or the MRP approach is more appropriate. In order to understand the concepts of dependent and independent demand items, we explain them as follows.

a. Dependent Demand Items

According to Baily (1987), dependent demand items are items that depend on demand for the product scheduled to be produced. Baily (1987) adds that different methods, such as demand forecasting using moving averages and exponential smoothing, are not appropriate and lead to either shortages or excessive stocks. The calculation of order quantities, in the way it was applied to other types of items, is also not appropriate for these items.

Silver et al. (1998) talk about this in the explanation of multi-echelon situations, in which “any specific piece of equipment requires a particular set of components” (p. 511). In COTECMAR, specific projects—such as shipbuilding, overhauling, transformation, or dismantling—require specific items unique for those projects, or a certain quantity of regular items that go beyond the regular quantity demanded. Although these specific projects are part of the ordinary business, they are known in advance and make it possible to conduct a replenishment plan. This is not the case for the repair process, in which the items or materials that are needed are determined once the technicians are already working on the system.

For dependent items, “requirements for parts and materials for the manufacture of a product to meet production schedules should be planned together as a single group, not as a lot of independent individual items. This is called Materials Requirement Planning (MRP).” (Baily, 1987, p.120)

MRP can involve thousands of items that have complications, such as varying lead times and demand. The first step of the MRP process is to establish a master production schedule, which is a planned out schedule showing what products, and what quantities of them, are needed to be completed by what dates. This schedule is usually listed on a weekly basis for three months, and then on a monthly basis for the next nine months. (Baily, 1987)

Then, the master production schedule should be expanded and include a detailed requirement of all the items needed to create each product. This is done by establishing the Bill of Materials (BOM). The Bill of Materials for a particular product lists all of the items needed, along with their quantities, to produce this specific product. It is sometimes referred to as the parts list. The Bill of Materials should be done on each product listed in the master production schedule. The planning of item ordering for the net requirements of each product should take into account the lead time needed, so that the items ordered arrive on time for production to meet the required date to finish the product (Baily, 1987). This is the way that MRP deals with dependent demand items.

b. Independent Demand Items

This project focuses on independent demand items data for the application of the models. According to Zipkin (2000), independent demand items are those for which there is no supply-demand link between them, and their processes are different. These items satisfy the assumptions of the EOQ model (or, if some of the assumptions are violated, these violations may be relaxed in some way). Items with this attribute are required on a regular basis for some production processes, mostly for repairs. Therefore, the demand does not depend on a special or temporary situation. Concurring with Zipkin (2000), we can control each of these kinds of items, separately from the others, and apply the EOQ and ROP models and control the inventory with the obtained results.

In order to refine the demand data, it is necessary to remove the items that belong to specific projects, such as shipbuilding or overhauling, since this constitutes dependent demand. For this purpose, we analyze each of the items in the Warehouse Transactions data file. There are columns in this file that provide information for the project code, project name, transaction reference, and work order. However, there is a lack of information in some of the important columns, such as project name, due to the incomplete fields that warehouse employees sometimes leave when they are registering the transactions.

We use tools such as Excel pivot tables to determine what projects are a part of larger projects that represent dependent demand. The pivot tables give us the percentage of consumption of each project out of the total demand. High percentages of consumption are looked into more carefully, because they may belong to large projects. With this information, we review the data to find the name or type of project. Some projects have a single project code. Other projects have multiple project codes for several reasons: because they are related to two or more vessels, because they are done in multiple stages, or because they have different work areas on the same project (i.e., fresh water system and propulsion system). Another characteristic of these kinds of projects is that they span a long period; most of the time they last more than six months. Based on our examination of the data, we found the following projects, with their codes, that have been completed during the period that our data covers. These projects are determined to have dependent demand; therefore, they drive the demand according to their own Bill of Material, so inventory to meet this demand can be ordered in advance, according to the MRP approach. Thus, in order to focus on our research project scope—independent demand items, the following projects are removed from our demand data:

- Submarines-overhauling: 855, 796.
- Support River Patrol (PAF)-shipbuilding: 296, 297, 845, 846, 903, 920.
- "Vicky B" - double hull: 539.
- Frigates-overhauling: 102, 113, 123, 125, 128.
- Offshore Patrol Vessel-shipbuilding: 840, 1002, 1082.
- "Manta Bay" Tanker Vessel-Overhauling: 1064.
- River Patrol Boat-shipbuilding: 828, 835, 836, 837.

Furthermore, all investment projects (such as road pavement or facility construction) are also excluded for the same reason as the projects above: these investments are planned in advance, so it is possible to conduct replenishment planning. We do not find projects of this kind by analyzing information about consumption. These projects do not have work orders like repair or shipbuilding projects. However, they have an administrative cost center that is characterized with a letter "P," and a four-digit number that always begins with "6" (i.e., P6497).

The remaining data relates to repair processes. These projects are short in execution and occur fairly regularly over time, without enough advanced notice for planning. There are two different kinds of situations with repair projects. One is that demand for repairs is not known in advance. The other situation is that the parts required for each repair are not known until the process starts or is underway. These repairs are the source of the independent demand items. We treat them as independent because they do not have the predictability and advanced notice of demand like the shipbuilding projects.

After filtering the data, we see all the data for each item via their transaction records. We group all the transaction records by month to determine monthly demand and monthly standard deviations for all of the items. With these groupings, we have demand with a time measure, and we can scale it to any time unit of measurement we could need for our calculations (i.e., daily, weekly, or annual demand). Table 8 shows the average monthly demand, standard deviation, and the coefficient of variation for each of the items. Note that, once the dependent demand quantities were removed, no independent demand for Mineral Copper Slag remained at Mamonal (Item 5). For this reason, this item is removed from the items that are going to be analyzed using EOQ model in the next section.

ITEM	NAME	WAREHOUSE	AVERAGE	STDEV	CV
1	NAVAL STEEL SHEET	Mamonal	10,317.53	12,793.66	1.24
2	FLUORESCENT LAMP	Bocagrande	0.57	2.30	4.03
3	WELDING 1/8"	Mamonal	1,241.61	836.04	0.67
4	ANTICORROSIVE EPOX	Mamonal	85.29	69.65	0.82
5	MINERAL COPPER SLAG	Mamonal	0	0	0
6	ADJUSTER FOR EPOXY	Mamonal	23.82	11.64	0.49
7	MINERAL COPPER SLAG	Bocagrande	13,207.75	13,631.47	1.03
8	CATALYST FOR EPOX	Mamonal	113.41	86.87	0.77
9	WELDING 5/32"	Mamonal	807.49	636.57	0.79
10	AGA SOL	Mamonal	1,547.76	1,001.81	0.65
11	CATALYST FOR EPOX	Bocagrande	55.81	43.10	0.77
12	POLY EPOX GREY	Bocagrande	7.02	22.71	3.23
13	SAFETY BOOTS SIZE 40	Mamonal	13.84	13.03	0.94
14	ANGLE C/S 1/4" X 2"	Mamonal	5.04	11.73	2.33
15	WHITE GELCOAT	Mamonal	20.45	26.25	1.28
16	SAFETY BOOTS SIZE 41	Mamonal	11.73	12.06	1.03
17	ANGLE C/S 1/4" X 2"	Bocagrande	4.67	7.14	1.53
18	FLANGE SLIP ON 6"	Mamonal	6.51	16.77	2.58
19	SUPER NYLON ROPE	Mamonal	21.33	41.07	1.93
20	GALVANIZED STEEL SHEET	Mamonal	1.57	5.70	3.63
21	WELDING 3/32"	Bocagrande	21.41	26.40	1.23
22	SAFETY BOOTS SIZE 41	Bocagrande	7.37	6.26	0.85
23	NON-CONDUCTING TAPE	Mamonal	16.94	17.59	1.04
24	FREON 22	Bocagrande	39.80	46.87	1.18
25	PLATE C/S 1/4" X 2"	Mamonal	43.88	94.85	2.16
26	PIPE C/S 1" SEAMLESS	Bocagrande	11.16	27.34	2.45
27	SCREW HEX GALVANIZED	Bocagrande	7.59	33.73	4.44
28	CABLE	Mamonal	19.39	79.59	4.11
29	PIPE C/S 1" SEAMLESS	Mamonal	9.95	18.13	1.82
30	ARMORED GLASS	Mamonal	0.02	0.14	7.00
31	CABLE	Bocagrande	11.94	26.77	2.24
32	SCREW HEX STAINLESS	Mamonal	3.27	10.85	3.32
33	NYLON ROPE 3/4"	Mamonal	1.10	5.43	4.93
34	STONE FOR FRICTION	Mamonal	15.80	15.84	1.00
35	BEARING	Bocagrande	1.12	1.63	1.45

Table 8. Average and Standard Deviation of Demand

We observe a high variation of demand based on the ratio $\sigma_L/\bar{x}_L$ suggested by Silver et al. (1998). This ratio, shown in the CV column of Table 8, is used in order to consider using a different approach rather than an approximation for normal distributions. According to them, if the ratio is greater than 0.5, we should consider using a different distribution of demand, such as the Gamma. In our analysis, all items—with the exception of the "Adjuster"—have a ratio greater than 0.5. Most values were significantly higher than 0.5.

In order to know the distribution, and to test if the normal distribution fits our demand data, we make some tests using the goodness-of-fit test of the "crystal ball" risk-analysis software application. This allows us to know the kind of distribution that best fits the set of observations in our demand data for each item. Furthermore, it shows us how much (and to what side) the data is skewed.

After drawing all the distribution for all of the items, we find that they have different kinds of distributions, such as lognormal, weibull, beta, maximum extreme, and logistic. None of the items have normal distribution. Figures 7 and 8 show examples of the distribution of two items.

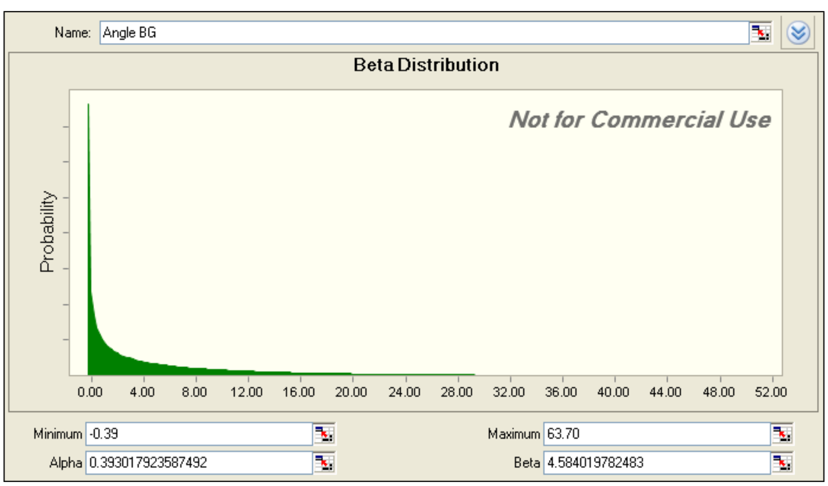

Figure 7. Beta Distribution Goodness-of-Fit test for "Angle" Item Demand

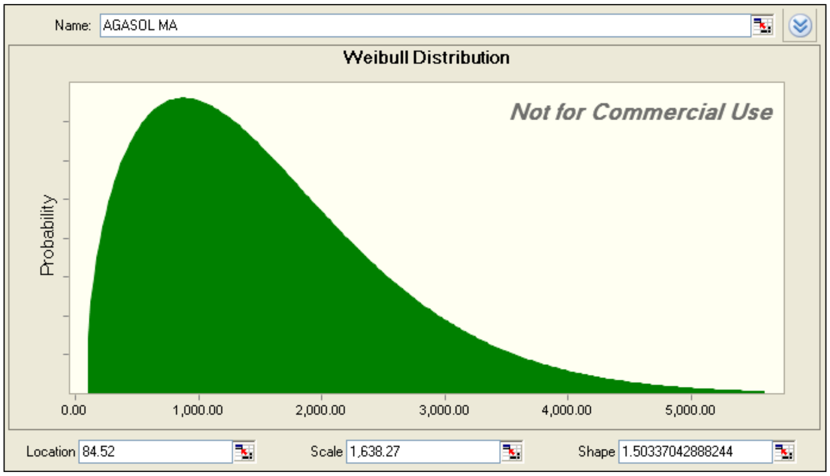

Figure 8. Weibull Distribution Goodness-of-Fit test for “Agasol” Item Demand

2. Lead Time

In order to calculate the order lead times, we use the Purchase Order data file. We filter all purchase orders made for an item, and find the lead time by subtracting the purchase order creation date from the supplier delivery dates. Lead times from suppliers have a regular time frame; however, there is some variation (due to unique cases) that makes it necessary to refine the data.

3. Refining the Data

While going through the immense amount of data we have, we encounter numbers that are very far from the norm, or outliers. This is especially evident in the data concerning demand and lead times. This creates a bit of a problem for COTECMAR’s management, because it distorts the real picture and the outlying numbers affect our averages greatly. We recognize that some of these outlier numbers are due to typos and others might be due to extraordinary circumstances. Therefore, we want a way to keep these numbers out of our calculations, in order to make our averages more realistic.

Instead of removing the numbers in an arbitrary way, we want to follow an acknowledged procedure to know exactly which numbers we should consider as outliers.

According to Keller (2009), there is a way to recognize which numbers are to be considered outliers within a certain data set. The procedure described can be achieved by following these steps:

1. Calculate the first (lower) and third (upper) quartiles of a data set.
2. Calculate the inter-quartile range by subtracting the lower quartile from the upper quartile.
3. Multiply 1.5 by the inter-quartile range.
4. Add the product of step 3 to the upper quartile. This gives you the upper limit of the numbers you should consider in your data set. Any number above this should be considered as outlier; hence, it can be discounted.
5. Subtract the product of step 3 from the lower quartile. This gives you the lower limit of the numbers you should consider in your data set. Any number below this should be considered as an outlier; hence, it can be discounted.

For instance, the lead times data set for the item "Copper Slag" are {56, 5, 1, 1, 13, 13, 47, 20, 65, 15, 17, and 97}. The steps to determine the outlying numbers in this data set are explained in the following process:

1	Upper quartile	53.75
2	Lower quartile	7
3	(upper quartile) - (lower quartile)	46.75
4	[(upper quartile) - (lower quartile)]*1.5	70.125
5	Upper quartile + Product of step 4	123.88
6	Lower quartile - Product of step 4	-63.13

The previous calculation shows that any numbers that are above 123.88 and below -63.13 can be considered outliers. We can see that we do not have any outlying numbers in this data set; thus, no numbers should be discounted. We use this method for all of the data sets that we think are greatly affected by outlier numbers.

Table 9 shows the calculated lead times for each item after outliers have been removed.

No.	Name	Average Lead Time	Std. Dev. Lead Time
1	NAVAL STEEL SHEET	6.51	6.19
2	FLUORESCENT LAMP	46.20	34.25
3	WELDING 1/8"	3.03	2.82
4	ANTICORROSIVE EPOX	6.11	3.54
5	MINERAL COPPER SLAG	29.17	30.23
6	ADJUSTER FOR EPOXY	5.60	3.17
7	MINERAL COPPER SLAG	29.17	30.23
8	CATALYST FOR EPOX	6.31	3.58
9	WELDING 5/32"	2.76	2.78
10	AGA SOL	3.36	2.94
11	CATALYST FOR EPOX	6.31	3.58
12	POLY EPOX GREY	7.33	4.24
13	SAFETY BOOTS SIZE 40	22.18	19.97
14	ANGLE C/S 1/4" X 2"	3.86	2.94
15	WHITE GELCOAT	7.37	4.65
16	SAFETY BOOTS SIZE 41	22.56	19.58
17	ANGLE C/S 1/4" X 2"	3.86	2.94
18	FLANGE SLIP ON 6"	3.50	2.79
19	SUPER NYLON ROPE	8.18	7.56
20	GALVANIZED STEEL SHEET	6.34	5.34
21	WELDING 3/32"	2.40	1.43
22	SAFETY BOOTS SIZE 41	22.56	19.58
23	NON-CONDUCTING TAPE	5.09	3.80
24	FREON 22	4.25	4.00
25	PLATE C/S 1/4" X 2"	3.47	2.75
26	PIPE C/S 1" SEAMLESS	4.92	3.15
27	SCREW HEX GALVANIZED	5.36	3.68
28	CABLE	4.09	2.98
29	PIPE C/S 1" SEAMLESS	4.92	3.15
30	ARMORED GLASS	49.00	21.32
31	CABLE	4.09	2.98
32	SCREW HEX STAINLESS	4.70	3.32
33	NYLON ROPE 3/4"	11.20	12.03
34	STONE FOR FRICTION	6.25	5.14
35	BEARING	3.21	2.63

Table 9. Calculation of Lead Times per Unit per Item

B. COST RELATED ANALYSIS

In this section, we continue determining the variables to be used in the equations and explain how each one is calculated according to the existing data

1. Holding Cost per Unit

Inventory holding costs are the costs incurred by the Corporation in order to hold the items in the warehouse. In this carrying cost, we may include the opportunity cost of using the money to buy inventory instead of use it in some interest-earning financial investments. In order to calculate the carrying costs, we use prior research created in COTECMAR, in which they estimate the warehousing costs.

In the prior research estimation, Arango et al. (2012) classify the expenditures in three groups: warehousing, handling, and other expenditures. Warehousing includes property costs, depreciation of the building, rent, maintenance, and repairs. Handling includes consumption of fuels and lubricants. It also includes depreciation of communication equipment, machinery, and furniture. Furthermore, it includes labor, office supplies, and transportation and freight. Finally, other expenditures include taxes, licenses, insurance, services, damages, and obsolescence.

Some of the costs determined in that research are incurred regardless of the level of inventory. For this reason, we only take account of the relevant costs incurred on each replenishment cycle according to the inventory quantity. This leads us to take account of only some of the costs that were taken in the previous research.

In the warehousing cost, we include maintenance and repairs. In the handling costs, we include consumption of fuels and lubricants, office supplies, and transportation and freight. Finally, in the other expenditures, we include taxes, insurance, damages, and obsolescence. Hence, we removed all of the fixed and sunk costs that will be incurred either way.

The average monthly warehousing cost is divided by the average monthly value of the total inventory, and the result is 0.443%. The opportunity cost is given by the ninety days deposit certificate interest rate used in COTECMAR financial investment, which is 5.44%. Therefore, the total carrying cost is the sum of the two percentages, which is 5.883%. We are going to apply this percentage to the unit price of each item to get the carrying cost per unit per year. Table 10 shows the holding cost calculation per unit per item,

based on the carrying cost percentage multiplied by the unit variable cost of the item.

No.	Name	Unit Measure	Warehouse	Unit cost (COP)	Holding Cost (COP)
1	NAVAL STEEL SHEET	Kilogram	MA	1,962.00	115.42
2	FLUORESCENT LAMP	Unit	BG	560,884.49	32,996.83
3	WELDING 1/8"	Kilogram	MA	3,943.09	231.97
4	ANTICORROSIVE EPOX	Gallon	MA	41,463.18	2,439.28
5	MINERAL COPPER SLAG	Kilogram	MA	549.37	32.32
6	ADJUSTER FOR EPOXY	Keg (5 Gal)	MA	105,036.32	6,179.29
7	MINERAL COPPER SLAG	Kilogram	BG	549.37	32.32
8	CATALYST FOR EPOX	¼ Gal	MA	20,354.75	1,197.47
9	WELDING 5/32"	Kilogram	MA	3,945.66	232.12
10	AGA SOL	Kilogram	MA	2,019.03	118.78
11	CATALYST FOR EPOX	¼ Gal	BG	20,354.75	1,197.47
12	POLY EPOX GREY	Gallon	BG	58,744.76	3,455.95
13	SAFETY BOOTS SIZE 40	Pair	MA	81,898.88	4,818.11
14	ANGLE C/S 1/4" X 2"	Unit	MA	62,695.35	3,688.37
15	WHITE GELCOAT	Kilogram	MA	14,528.48	854.71
16	SAFETY BOOTS SIZE 41	Pair	MA	84,260.72	4,957.06
17	ANGLE C/S 1/4" X 2"	Unit	BG	62,695.35	3,688.37
18	FLANGE SLIP ON 6"	Unit	MA	44,878.62	2,640.21
19	SUPER NYLON ROPE	Meter	MA	31,885.25	1,875.81
20	GALVANIZED STEEL SHEET	Unit	MA	59,853.89	3,521.20
21	WELDING 3/32"	Kilogram	BG	4,409.11	259.39
22	SAFETY BOOTS SIZE 41	Pair	BG	84,260.72	4,957.06
23	NON-CONDUCTING TAPE	Roll	MA	9,587.10	564.01
24	FREON 22	Pound	BG	3,639.20	214.09
25	PLATE C/S 1/4" X 2"	Meter	MA	5,425.48	319.18
26	PIPE C/S 1" SEAMLESS	Meter	BG	11,159.71	656.53
27	SCREW HEX GALVANIZED	Unit	BG	808.92	47.59
28	CABLE	Meter	MA	3,682.27	216.63
29	PIPE C/S 1" SEAMLESS	Meter	MA	11,159.71	656.53
30	ARMORED GLASS	Unit	MA	689,980.45	40,591.55
31	CABLE	Meter	BG	3,682.27	216.63
32	SCREW HEX STAINLESS	Unit	MA	458.10	26.95
33	NYLON ROPE 3/4"	Meter	MA	8,183.53	481.44
34	STONE FOR FRICTION	Unit	MA	261.62	15.39
35	BEARING	Unit	BG	9,734.68	572.69

Table 10. Calculation of Holding Cost per Unit per Item

2. Fixed Cost per Order

In order to calculate the fixed cost, we use prior research created in COTECMAR in which Arango et al. (2012) estimate the average fixed cost of creating a single purchase order. Table 11 shows the calculated fixed cost per purchase order for different processes. The variation in cost is due to involvement of different departments in a given purchase order that depends on the critically, functionality, and sensitivity.

For instance, in a shipbuilding purchase order process, the following parties are involved: the Production department, the project manager, the logistic coordinator, research and development, the purchasing analyst, the purchasing head, and—depending on the price—the contract office. The Production department makes the requisition. The project manager analyzes the budget and approves it. The logistic coordinator analyzes the requirement and coordinates the technical requirements for that purchase with research and development employees. The purchasing analyst makes the order. If needed, lawyers at the contract office review the contracts and make suggestions. Finally, the purchasing head signs off the purchase order.

In other instances, such as repairs, production departments make the requisition with the approval of the project manager directly to the purchasing analyst. The purchasing analyst makes the order and the purchasing head signs it off. It is evident that both instances use different processes to conduct their purchase order; therefore, the fixed prices are considerably different. Fixed costs include other expenditures, such as: office supplies, transportation, utilities, depreciation of property and equipment, taxes, and insurance, etc.

Process	**Cost (COP)**
Repairs Mamonal	18,676.05
Shipbuilding	141,076.42
Repairs Bocagrande	24,939.09
International orders	171,627.39
Administrative orders	34,878.77
Investment orders (PP&E)	87,151.31
Frigates Orders	72,009.21
Submarines Orders	58,770.00

Table 11. Fixed Order Cost per Order per Process (From Arango et al., 2012)

In the fixed cost per order, we only consider Repairs Mamonal, Repairs Bocagrande, Administrative Orders, and Investment Orders. We do not consider the rest for valid reasons. Shipbuilding order cost is not considered in the cost per order calculation because the items we have in our sample do not require departments such as Research and Development and the project manager, which contributes to the high cost of shipbuilding purchasing orders. Although the items we have in our sample are considered shipbuilding projects, they do not require the process that makes up the shipbuilding cost. For instance, boots are considered to be part of shipbuilding projects;

however, the process of purchasing them does not require the involvement of different department within the corporation. Therefore, the process of purchasing them has the exact same fixed-cost structure as the "Repairs" fixed cost.

Frigates and International Orders have an employee involvement in the purchasing process that is similar to shipbuilding. Purchasing orders for frigates involves research and development, and technical committees, working with the Navy. International orders involve foreign trade office employees. Thus, they are also not considered in our fixed cost per order calculation, for the same reasons explained for shipbuilding. Furthermore, the data received do not involve any international purchases.

As with the holding cost, some of the components of the fixed cost determined in that research are incurred regardless of the volume of purchase orders. For this reason, we only take account of the relevant costs incurred each time an order is placed. This leads to taking account of only some of the costs that were considered in the previous research.

From the costs determined in the prior research, we include travel allowance, legal expenditures, office supplies, and taxi expenditures. We exclude labor, technical services, and oil and lubricants, because they are incurred either way. We note that the main driver of the ordering cost, which is shown in Table 11 taken from the previous research, is labor. After refining the data and removing this cost, along with the other irrelevant costs, we arrive at a lower cost that is the same across all processes. The fixed order relevant cost per purchase order is COP 235.42.

3. Shortage Cost

As Coleman (2000) notes, there are many examples of tangible shortage costs per unit that can be calculated. Some examples are the cost of premium freight when rushing the delivery of an item, or the extra cost for a substitute. However, the definition of this cost could be vague or imprecise because it may include costs such as loss of contribution margin on sales, or loss of a company's goodwill.

In COTECMAR, this cost is not stated for several reasons. First, the number of units used in a single project could be hundreds (or even thousands), and the impact of a single item is minimal. Second, production works are scheduled in the order of vessel working space released, workers availability, and raw material availability. Thus, if there is stockout of some items, the project manager immediately reschedules the works in order to avoid idle time for the workers. Third, an actual shortage cost (such as a penalty from a customer for a delay in a given product) is caused by specific equipment or a unique item. These cases are isolated to special situations that are not part of the scope of this project.

However, when there is a shortage of an item, there is an extra cost incurred when it is purchased from another supplier. This extra cost is the difference of the overpriced item from the usual price COTECMAR pays on a regular basis. For instance, if COTECMAR purchases item X for $100, and there is a stockout without an opportune replenishment from the regular supplier Y, COTECMAR is sometimes forced to buy from another supplier Z. Supplier Z sells item X for $130. Thus, the shortage cost per unit for item X is going to be $30. In other cases, when COTECMAR forces supplier Y to rush the delivery of item X, this premium freight is negotiated and sometimes paid by the supplier. However, this freight cost is negligible in order to consider it a constant shortage cost. Situations for which the change in freight cost is significant are rare, identified cases that are managed separately.

Silver, Pyke, and Peterson (1998) present four cases on which we can rely to determine safety stocks based on minimization of costs. These cases consider different forms of shortage costs. One cost is determined fixed per stockout occasion; this fixed value is independent of the quantity or the magnitude of the stockout. This approach does not fit the shipyard, due to the variety of items. A second cost is a charge per unit short per unit time. This approach is used when there is a cost associated with a constant cost that will be incurred while the shortage lasts. This approach does not apply to the shipyard, because production does not stop while waiting for an item. A third cost is a charge per customer line item short; this applies to a line item backorder. This is not an accurate measure for the shipyard as long as number of lines are not specified or fixed for every requisition or purchase order. Finally, the last cost mentioned is the fractional charge per unit short. This is to assign a fixed cost or fraction to the unit variable cost of the item short. This is the approach that best fits in the shipyard, because the overcharge is made based on the item short (based on its unit cost) and is independent of other cost factors. This fractional charge is denoted as B_2.

For the calculation of the shortage cost of our items, we take the information from the Purchase Orders data file and check the unit price. We take the regular price COTECMAR pays for a specific item by calculating the most frequently occurring price in our range of data. We review carefully to ensure that the most repeated number is really the regular price, and is not a situation of high demand in old years with a price lower than the actual in recent years. This situation may distort the regular price calculation because even if the demand is low in recent years, the regular price is going to be not the most frequent price, but the recent one. After determining the regular price, we calculate the maximum price COTECMAR had paid for the same item by returning the largest value in our set of data. As before, we review carefully every specific situation to make sure that the highest price is an actual price paid by COTECMAR. This is because there could be a typo during the elaboration of the purchase order, a mistake in the unit of measurement (i.e., gallons instead of liters), or a unique purchase with some specifications that make the item more expensive. Even though the maximum price is not always the price COTECMAR is obligated to pay, and may be sporadic, there is a probability of requiring the item from that given expensive supplier. Thus, it is going to be considered as a possible shortage cost.

For instance, the regular price COTECMAR pays for a kilogram of AGASOL is COP 2,000, and the maximum price that has been paid is COP 2,570. This is an increase of 29% of the normal price. Therefore, the shortage cost for AGASOL is going to be COP 570. Table 12 shows the calculation of the shortage cost per item.

There are some cases in which the increasing percentage is very high, in some cases doubling the regular price. This happens when there is an urgent need of the item. It is then usually purchased from any retailer that has the item available for immediate delivery. Such retailers are generally home improvement stores, and their prices are considerably high compared to the distributors or factories from which COTECMAR buys directly.

There is also a special case with the POLY EPOX GREY item (Item 12), on which the shortage cost is zero. This is because there is no change in price in the historical data we analyzed, so a shortage cost could not be identified. Therefore, this item cannot be analyzed in the equations because we cannot calculate Service Level with a denominator of zero in the equation. However, as explained in the next section, this item is removed from the items that are going to be analyzed using EOQ due to its variability.

No.	Name	Unit Measure	Regular price (COP)	Maximum	Shortage fraction	Shortage cost (COP)
1	NAVAL STEEL SHEET	Kilogram	2,199.48	3,250.00	0.48	1,050.52
2	FLUORESCENT LAMP	Unit	593,338.32	675,000.00	0.14	81,661.68
3	WELDING 1/8"	Kilogram	3,800.00	7,800.00	1.05	4,000.00
4	ANTICORROSIVE EPOX	Gallon	39,711.00	89,560.00	1.26	49,849.00
5,7	MINERAL COPPER SLAG	Kilogram	531.34	630.00	0.19	98.66
6	ADJUSTER FOR EPOXY	Keg (5 Gal)	98,885.00	154,397.00	0.56	55,512.00
8,11	CATALYST FOR EPOX	¼ Gal	19,710.00	29,982.00	0.52	10,272.00
9	WELDING 5/32"	Kilogram	3,800.00	9,750.00	1.57	5,950.00
10	AGA SOL	Kilogram	2,000.00	2,570.00	0.29	570.00
12	POLY EPOX GREY	Gallon	58,780.00	58,780.00	-	-
13	SAFETY BOOTS SIZE 40	Pair	80,633.00	140,000.00	0.74	59,367.00
14,17	ANGLE C/S 1/4" X 2"	Unit	72,700.00	82,944.00	0.14	10,244.00
15	WHITE GELCOAT	Kilogram	13,041.00	20,000.00	0.53	6,959.00
16,22	SAFETY BOOTS SIZE 41	Pair	100,000.00	140,000.00	0.40	40,000.00
18	FLANGE SLIP ON 6"	Unit	32,900.00	68,000.00	1.07	35,100.00
19	SUPER NYLON ROPE	Meter	32,650.05	39,488.00	0.21	6,837.95
20	GALVANIZED STEEL SHEET	Unit	67,000.00	96,900.00	0.45	29,900.00
21	WELDING 3/32"	Kilogram	4,100.00	10,500.00	1.56	6,400.00
23	NON-CONDUCTING TAPE	Roll	9,960.00	15,100.00	0.52	5,140.00
24	FREON 22	Pound	3,484.60	6,000.00	0.72	2,515.40
25	PLATE C/S 1/4" X 2"	Meter	5,850.00	6,800.00	0.16	950.00
26,29	PIPE C/S 1" SEAMLESS	Meter	10,571.06	20,305.00	0.92	9,733.94
27	SCREW HEX GALVANIZED	Unit	995.00	1,724.00	0.73	729.00
28,31	CABLE	Meter	3,400.00	5,200.00	0.53	1,800.00
30	ARMORED GLASS	Unit	698,541.75	805,078.00	0.15	106,536.25
32	SCREW HEX STAINLESS	Unit	507.00	825.00	0.63	318.00
33	NYLON ROPE 3/4"	Meter	6,552.00	9,300.00	0.42	2,748.00
34	STONE FOR FRICTION	Unit	200.00	500.00	1.50	300.00
35	BEARING	Unit	11,000.00	15,086.00	0.37	4,086.00

Table 12. Calculation of Shortage Cost per Unit

In the previous section, we determined the needed variables and their values to be used in the inventory strategy equations. In the next sections, we determine the equation to be used according to each class of inventory, and depending on the assumptions and rules for each approach.

C. INVENTORY MANAGEMENT FOR INDEPENDENT DEMAND ITEMS

This section contains the definition of the equations and the analysis of the assumptions, requirements, and rules for each equation. These equations are the Economic Order Quantity, the Service Level, and the Reorder Point.

1. Economic Order Quantity Equation Definition

The basic EOQ equation explained in Chapter II has some assumptions that must be met to be valid. Some of the assumptions are violated by COTECMAR, according to the data we have; thus, it is necessary to analyze each assumption and determine how to relax it. The assumptions and their analysis are explained as follows:

- *The demand is given in the form of a planning horizon to be satisfied.* This is when the parts that are needed are known in advance for a specific period and their orders are planned accordingly. Conversely, at the shipyard the demand is identified on a short-term basis once a sale is done, and cannot be given in the form of a planning horizon. However, this situation is addressed with the determination of safety stocks.
- *The demand is known*. The demand is not known because item requirements are identified once starting repair operations. This situation is also addressed with the determination of safety stocks.
- *The requirements must be satisfied at the beginning of the period*. Even if it is preferable that the required items are obtained at the beginning of the period (before starting repair operations), this is not a constraint because items can be received during the operation.
- *The replenishment lead time is known with certainty*. Although the suppliers have regular lead times, there is some variability due to multiple factors such as: transportation delays, stockouts at the supplier, or uncontrollable situations. However, this situation is also addressed with the determination of safety stocks.

- *The entire order quantity is delivered at the same time*. In fact, partial deliveries do occur on occasion; however, because this situation occurs rarely, we assume that entire order quantities are delivered at the same time.

To relax these assumptions, an approach explained by Silver, Pyke, and Peterson (1998) to deal with items that have time varying demand is to use the basic EOQ. This is when there is a low variability pattern of the demand.

a. Continuous vs. Periodic Review

There are two approaches to inventory review that we can use in inventory management strategies: continuous or periodic review. For COTECMAR, we use continuous review because replenishment decisions are made at any moment with the updated status of the items, using the ERP software. Periodic review happens for consignment inventories, where, according to the consignment agreements, there is a monthly review between the consignor and the consignee in order to quantify the consumed items and the new replenishment requirements. However, in the case of a stockout, COTECMAR may ask the consignor to replenish at any time, or they may conduct a purchase with any other supplier without having to wait for the next review period.

This project only focuses on continuous review, because we want to seek inventory strategies with suppliers that COTECMAR does not have agreements with. Furthermore, it is more frequent that a stockout of an item occurs if it is not in a consignment inventory.

b. Model Selection

After seeing and analyzing the data for COTECMAR, we realize that the shipbuilding industry is unique, in the sense that its demand and lead times are much more complicated than many other industries. The demands do not follow a certain pattern or a normal distribution, making it especially challenging to apply a specific method to it.

According to this uniqueness, we need to identify the portion of data to which the EOQ models can be applied. In the demand section, we have removed the quantities that belong to special projects because those are dependent demand quantities. However, the independent demand has some characteristics that make it difficult for the models to be used. Therefore, we proceed by removing those quantities of demand, as well as entire items that are still special cases. These special cases and special items may be treated individually.

First, we refine our demand data by identifying those peak demand quantities that go substantially out of the normal range. We suggest using those peak quantities as special cases that might have special replenishment decisions. Therefore, we remove the outliers in each item. This is done using the same method explained in the lead time section. Outliers are removed from the demand data to make sure that out-of-the-ordinary circumstances that rarely happen do not have a severe impact on our order quantities. In this case, substantially high quantities are to be treated outside of the EOQ calculation, and should be ordered upon request.

After refining the demand data, we proceed to calculate the coefficient of variation. The coefficient of variation will be the factor used in deciding the approach to determine the order quantities. In consideration of the kind of distribution of our demand, we suggest that if the coefficient of variation is 1 or below, the basic EOQ model is used. On the other hand, if the coefficient of variation is larger than 1, then these items should be considered as special items and analyzed separately by management, based on the unique case of each item.

These special items discussed above may be characterized as having long periods without demand and scattered demand occurrences. Another characteristic is an extremely high variation with no pattern. Figures 9 and 10 show time-series diagrams of a couple of special items. Galvanized Steel Item has a CV of 3.63 and Flange item has a CV of 2.58. These figures show the unique behavior of demand over time.

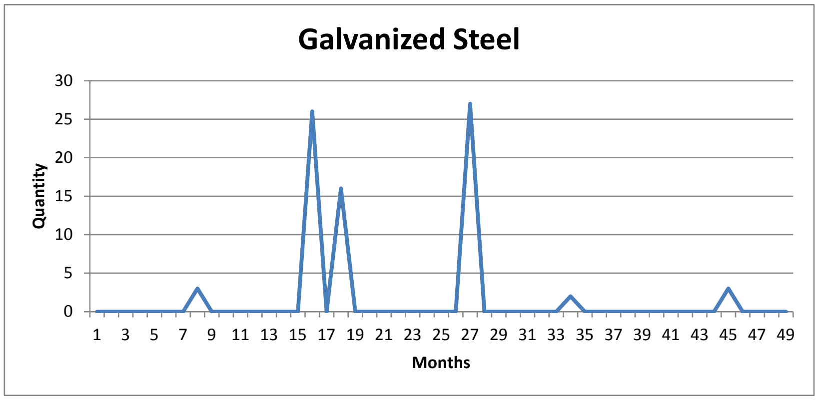

Figure 9. Monthly Demand of "Galvanized Steel" (Special Item)

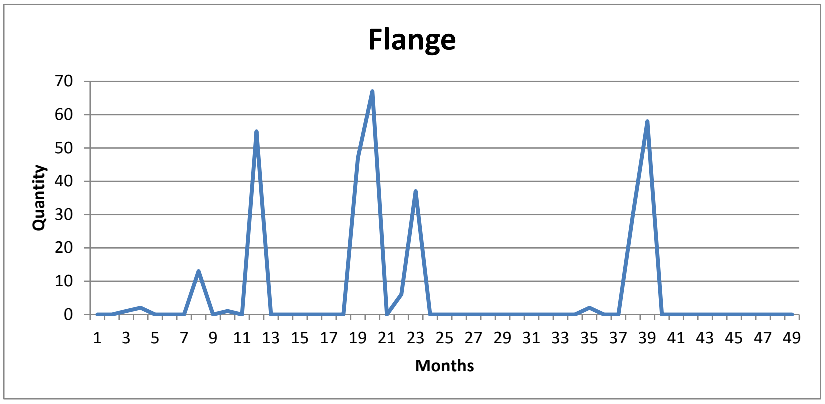

Figure 10. Monthly Demand of "Flanges" (Special Item)

In Figures 9 and 10, we observe the high variability of demand for both examples of special items. We also notice that the majority of demand over the months is zero, with no patterns distinguishable whatsoever. Therefore, we suggest that management analyzes those items separately, and that order upon request seems the best feasible course of action, especially when those items are expensive or perishable. If the items are inexpensive and not perishable, then a feasible inventory of the item can be kept in stock, in consideration of carrying cost. For this purpose, it is necessary to have certain agreements with vendors to minimize lead times and risk on replenishments.

Twenty of the items were categorized as special items[5], like the examples in Figures 9 and 10. The list of these items is shown in Table 13. In this table, we show the average monthly demand, standard deviation, and the coefficient of variation. We do not use the EOQ on these items for the reasons mentioned earlier.

No.	ITEM	WAREHOUSE	AVERAGE	STDEV	CV
2	FLUORESCENT LAMP	Bocagrande	0.57	2.30	4.03
5	MINERAL COPPER SLAG	Mamonal	-	-	-
12	POLY EPOX GREY	Bocagrande	7.02	22.71	3.23
14	ANGLE C/S 1/4" X 2"	Mamonal	2.05	2.80	1.37
15	WHITE GELCOAT	Mamonal	18.88	24.08	1.28
17	ANGLE C/S 1/4" X 2"	Bocagrande	3.62	4.90	1.35
18	FLANGE SLIP ON 6"	Mamonal	6.51	16.77	2.58
19	SUPER NYLON ROPE	Mamonal	21.33	41.07	1.93
20	GALVANIZED STEEL SHEET	Mamonal	1.57	5.70	3.63
24	FREON 22	Bocagrande	36.77	42.26	1.15
25	PLATE C/S 1/4" X 2"	Mamonal	43.88	94.85	2.16
26	PIPE C/S 1" SEAMLESS	Bocagrande	11.16	27.34	2.45
27	SCREW HEX GALVANIZED	Bocagrande	7.59	33.73	4.44
28	CABLE	Mamonal	19.39	79.59	4.11
29	PIPE C/S 1" SEAMLESS	Mamonal	9.95	18.13	1.82
30	ARMORED GLASS	Mamonal	0.02	0.14	7.00
31	CABLE	Bocagrande	11.94	26.77	2.24
32	SCREW HEX STAINLESS	Mamonal	3.27	10.85	3.32
33	NYLON ROPE 3/4"	Mamonal	1.10	5.43	4.93
35	BEARING	Bocagrande	0.80	1.07	1.33

Table 13. List of Special Items

In Table 14, we show the list of items that the basic EOQ model is going to be used for. This table also contains the average monthly demand, standard deviation, and the coefficient of variation. These independent demand items with regular quantity ranges may be characterized by their regular demand occurrences. Furthermore, their coefficient of variation are 1 or below. Figures 11 and 12 show time series diagrams for two of these regular items. These figures show a normal behavior of demand over time, even when variability is present.

[5] Special Items refers to Items with very high variation (Coefficient of Variation > 1)

No.	ITEM	WAREHOUSE	AVERAGE	STDEV	CV
1	NAVAL STEEL SHEET	Mamonal	8,441.64	8,720.79	1.00
3	WELDING 1/8"	Mamonal	1,241.61	836.04	0.67
4	ANTICORROSIVE EPOX	Mamonal	75.79	52.83	0.70
6	ADJUSTER FOR EPOXY	Mamonal	22.34	9.22	0.41
7	MINERAL COPPER SLAG	Bocagrande	13,207.75	13,631.47	1.00
8	CATALYST FOR EPOX	Mamonal	100.67	61.21	0.61
9	WELDING 5/32"	Mamonal	776.40	604.53	0.78
10	AGA SOL	Mamonal	1,547.76	1,001.81	0.65
11	CATALYST FOR EPOX	Bocagrande	49.89	32.57	0.65
13	SAFETY BOOTS SIZE 40	Mamonal	11.41	8.74	0.77
16	SAFETY BOOTS SIZE 41	Mamonal	9.35	7.39	0.79
21	WELDING 3/32"	Bocagrande	16.07	15.73	0.98
22	SAFETY BOOTS SIZE 41	Bocagrande	7.37	6.26	0.85
23	NON-CONDUCTING TAPE	Mamonal	14.83	14.51	0.98
34	STONE FOR FRICTION	Mamonal	15.80	15.84	1.00

Table 14. List of Independent Demand Items with Regular Quantity Ranges

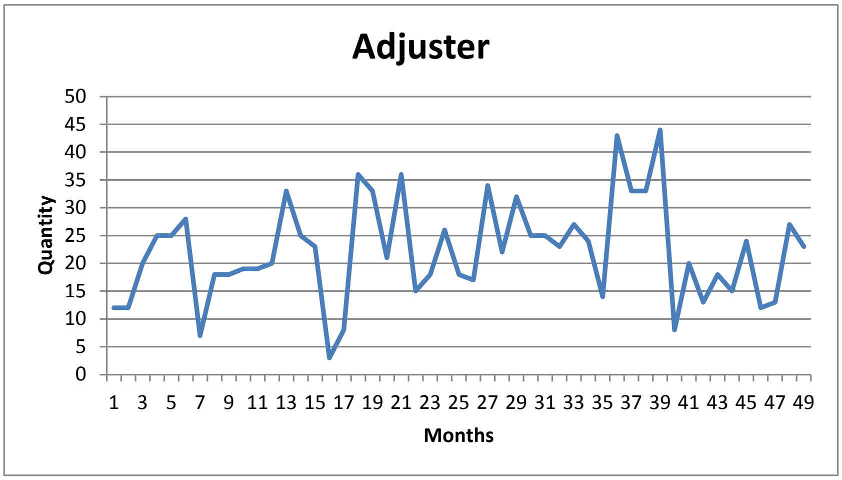

Figure 11. Monthly Demand of “Adjuster” (Regular Item)

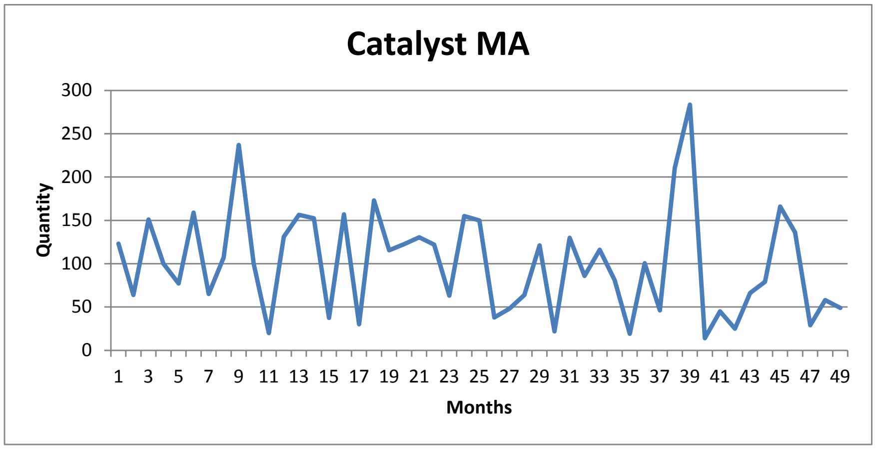

Figure 12. Monthly Demand of "Catalyst Mamonal" (Regular Item)

One important consideration in the analysis of these regular items is the ABC classification of the items and the different approaches to be used. The different approaches and derivations of the EOQ model used in each of the categories depend on some characteristics inherent to each item. Such characteristics might be: dollar usage, criticality of the item, volume, traceability, frequency, and scheduling, among many other characteristics. As our research progressed, the uniqueness of the shipyard industry became apparent to us. After refining the data and determining the portion of data that the inventory management models could be applied to, we found that most of the items lost their main characteristics. Therefore, the group of fifteen items are refined enough to share similar characteristics, making the distinctions used in the ABC categorization no longer applicable.

We used the ABC classification for items earlier in the project in Table 7 (Listing of Sample SKUs by Descending COP value); however, after removing the dependent demand of all of the items, they have lost some of the characteristics including much of the volume that drove the annual COP usage. Therefore, we now treat the items as if all are B and C items, and use the basic EOQ, SL, and RP models presented previously for B and C items. However, the ABC categorization may still be useful for management decisions that deal with special items that are out of the research scope. The following basic EOQ equation is used for items with relatively low variability:

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

c. Application

Table 15 shows the economic order quantity and the variables needed to calculate it. For example, for the EOQ calculation of Naval Steel (which is measured in kilograms), we take the values as follows: annual demand of 101,300 kilograms, fixed order cost of COP 235, and holding cost per unit per year of COP 115. We apply the values into the equation:

$$EOQ = \sqrt{\frac{2(101,300)(235)}{115}}$$

$$EOQ = 643$$

No.	Name	Unit Measure	WH	Annual Demand (D)	Fixed Cost per Order (COP) (A)	Holding Cost (COP) (r)	EOQ
1	NAVAL STEEL SHEET	Kilogram	MA	101,300	235	115	643
3	WELDING 1/8"	Kilogram	MA	14,899	235	232	174
4	ANTICORROSIVE EPOX	Gallon	MA	909	235	2,439	13
6	ADJUSTER FOR EPOXY	Keg (5 Gal)	MA	268	235	6,179	5
7	MINERAL COPPER SLAG	Kilogram	BG	158,493	235	32	1,520
8	CATALYST FOR EPOX	¼ Gal.	MA	1,208	235	1,197	22
9	WELDING 5/32"	Kilogram	MA	9,317	235	232	137
10	AGA SOL	Kilogram	MA	18,573	235	119	271
11	CATALYST FOR EPOX	¼ Gal.	BG	599	235	1,197	15
13	SAFETY BOOTS SIZE 40	Pair	MA	137	235	4,818	4
16	SAFETY BOOTS SIZE 41	Pair	MA	112	235	4,957	3
21	WELDING 3/32"	Kilogram	BG	193	235	259	19
22	SAFETY BOOTS SIZE 41	Pair	BG	88	235	4,957	3
23	NON-CONDUCTING TAPE	Roll	MA	178	235	564	12
34	STONE FOR FRICTION	Unit	MA	190	235	15	76

Table 15. Economic Order Quantity (EOQ)

After separating special items from regular ones, and applying the basic EOQ model to regular items, we can then move on to the determination of the service level and the reorder point.

2. Service Level

Once we determine how to calculate optimal quantities we can use the approach described by Coleman (2000), and discussed earlier in the literature review chapter, to figure out the correct service level. This calculation, shown below, uses holding cost, shortage cost, and the average annual demand and economic order quantities, all—of which have been determined in the previous section.

$$\text{Service Level} = 1 - \frac{\text{(Holding Cost per Unit per Year) (Order Quantity)}}{\text{(Shortage Cost per Unit) (Average Annual Demand)}}$$

Table 16 shows the service level and the variables needed to calculate it. For example, for the SL calculation of Naval Steel (which is measured in kilograms), we take the values as follows: annual demand of 101,300 kilograms, holding cost per unit per year of COP 115, shortage cost per unit of COP 1,051 and the calculated EOQ of 643. We apply the values into the equation:

$$1 - \frac{(115)(643)}{(1,051)(101,300)} = 99.93\%$$

No.	Name	Unit Measure	WH	Annual Demand	Holding Cost (COP)	Shortage Cost (COP)	EOQ	SL
1	NAVAL STEEL SHEET	Kilogram	MA	101,300	115	1,051	643	0.9993
3	WELDING 1/8"	Kilogram	MA	14,899	232	4,000	174	0.9993
4	ANTICORROSIVE EPOX	Gallon	MA	909	2,439	49,849	13	0.9993
6	ADJUSTER FOR EPOXY	Keg (5 Gal)	MA	268	6,179	55,512	5	0.9981
7	MINERAL COPPER SLAG	Kilogram	BG	158,493	32	99	1,520	0.9969
8	CATALYST FOR EPOX	¼ Gal.	MA	1,208	1,197	10,272	22	0.9979
9	WELDING 5/32"	Kilogram	MA	9,317	232	5,950	137	0.9994
10	AGA SOL	Kilogram	MA	18,573	119	570	271	0.9970
11	CATALYST FOR EPOX	¼ Gal.	BG	599	1,197	10,272	15	0.9970
13	SAFETY BOOTS SIZE 40	Pair	MA	137	4,818	59,367	4	0.9978
16	SAFETY BOOTS SIZE 41	Pair	MA	112	4,957	40,000	3	0.9964
21	WELDING 3/32"	Kilogram	BG	193	259	6,400	19	0.9961
22	SAFETY BOOTS SIZE 41	Pair	BG	88	4,957	40,000	3	0.9959
23	NON-CONDUCTING TAPE	Roll	MA	178	564	5,140	12	0.9925
34	STONE FOR FRICTION	Unit	MA	190	15	300	76	0.9794

Table 16. Service Level (SL)

3. Reorder Point

After determining service level, the reorder point can be calculated by using the basic method of Silver, Pyke and Peterson (1998) discussed in the literature review chapter. Because we have refined the demand data, and separated the dependent demand items and special quantity cases, we come up with a coefficient of variation less than or equal to one. Therefore, we assume normal distribution for lead time and demand. The equation to be used is as follows:

$$s = \bar{x}_L + k\sigma_{dLT}$$

Table 17 shows the reorder point and the variables needed to calculate it. For example, for the ROP calculation of Naval Steel (which is measured in kilograms), we take the values as follows: daily demand of 281.39 kilograms, lead time demand standard deviation of 1,592, average lead time of 7 days, lead time standard deviation of 6 days, and a safety factor of 3.196. The lead time demand standard deviation is calculated by scaling the monthly demand standard deviation as follows:

$$DailySTDEV = (MonthlySTDEV)*\sqrt{\frac{1}{30}}$$

The safety factor is calculated using the excel function NORMSINV of the service level calculated above. Finally, we calculate:

$$\sigma_{dLT} = \sqrt{(AverageLT*\sigma_d{}^2)+((AverageDailyDemand)^2*\sigma^2{}_{LT})}$$

For example, for Naval Steel we apply the values into the equation as follows:

$$(281.39)(7)+(3.196)(\sqrt{(7*1{,}592^2)+(281.39^2*6^2)}) = 15{,}960$$

No.	Name	Unit Measure	WH	Daily Demand ($\bar{X}_L$)	Daily Demand Stdev (σ_D)	Average lead time (LT)	lead time Stdev (σ_{LT})	Safety Factor (k)	SL	ROP
1	NAVAL STEEL SHEET	Kilogram	MA	281.39	1,592	7	6	3.196	0.9993	15,960
3	WELDING 1/8"	Kilogram	MA	41.39	153	3	3	3.204	0.9993	1,056
4	ANTICORROSIVE EPOX	Gallon	MA	2.53	10	6	4	3.189	0.9993	97
6	ADJUSTER FOR EPOXY	Keg (5 Gal)	MA	0.74	2	6	3	2.898	0.9981	18
7	MINERAL COPPER SLAG	Kilogram	BG	440.26	2,489	29	30	2.733	0.9969	64,528
8	CATALYST FOR EPOX	¼ Gal.	MA	3.36	11	6	4	2.862	0.9979	109
9	WELDING 5/32"	Kilogram	MA	25.88	110	3	3	3.251	0.9994	713
10	AGA SOL	Kilogram	MA	51.59	183	3	3	2.743	0.9970	1,183
11	CATALYST FOR EPOX	¼ Gal.	BG	1.66	6	6	4	2.749	0.9970	55
13	SAFETY BOOTS SIZE 40	Pair	MA	0.38	2	22	20	2.853	0.9978	39
16	SAFETY BOOTS SIZE 41	Pair	MA	0.31	1	23	20	2.687	0.9964	31
21	WELDING 3/32"	Kilogram	BG	0.54	3	2	1	2.658	0.9961	14
22	SAFETY BOOTS SIZE 41	Pair	BG	0.25	1	23	20	2.647	0.9959	25
23	NON-CONDUCTING TAPE	Roll	MA	0.49	3	5	4	2.432	0.9925	18
34	STONE FOR FRICTION	Unit	MA	0.53	3	6	5	2.041	0.9794	20

Table 17. Reorder Point (ROP)

D. FINDINGS

We begin our findings with a table summarizing the items analysis. Then, we categorize our findings using Demand, Price, Item, Lead Time, and Process Issues. The following are the findings.

1. Summary Table

Table 18 is a summary table explaining the transition that led us from our 35 sample items to the 15 items analyzed using the EOQ model. First, we took the total annual demand quantity and separated out the dependent demand quantities that belong to known-in-advance projects such as shipbuilding and overhauling. For these quantities we recommend to use MRP approach. The remaining quantities are independent demand items. We calculated the coefficient of variation (CV) to determine the suitable inventory management approach. For items with high variability (CV>1), we recommended separate analysis by management. For example, items with large CV typically have zero demand in most time periods and positive demand in only a few time periods. Thus, the management should try to determine the drivers of demand, i.e. what caused the positive demand. With this analysis in place, the management is in a position to better plan for the inventory of these items with high CV. The remaining 15 items are independent demand items with CV lower than 1. For these items, we recommended using the basic EOQ approach.

No.	Name	WH	Total Annual Demand Q	Dependent Demand Q	Appropriate Method for Dependent Quantity	Independent Demand Q	CV	Appropriate Method for Independent Quantity
1	NAVAL STEEL SHEET	MA	252,863.25	151,563.59	MRP	101,299.66	1.00	EOQ Model
2	FLUORESCENT LAMP	BG	278.67	271.81	MRP	6.86	4.03	Separate Analysis
3	WELDING 1/8"	MA	31,358.50	16,459.15	MRP	14,899.35	0.67	EOQ Model
4	ANTICORROSIVE EPOX	MA	2,613.75	1,704.30	MRP	909.45	0.70	EOQ Model
5	MINERAL COPPER SLAG	MA	165,890.00	165,890.00	MRP	-	0.00	Separate Analysis
6	ADJUSTER FOR EPOXY	MA	778.75	510.66	MRP	268.09	0.41	EOQ Model
7	MINERAL COPPER SLAG	BG	158,493.00	26,415.50	MRP	132,077.50	1.00	EOQ Model
8	CATALYST FOR EPOX	MA	3,541.13	2,333.08	MRP	1,208.04	0.61	EOQ Model
9	WELDING 5/32"	MA	17,812.50	8,495.75	MRP	9,316.75	0.78	EOQ Model
10	AGA SOL	MA	31,106.88	12,533.76	MRP	18,573.11	0.65	EOQ Model
11	CATALYST FOR EPOX	BG	2,502.50	1,903.78	MRP	598.72	0.65	EOQ Model
12	POLY EPOX GREY	BG	534.50	450.26	MRP	84.24	3.23	Separate Analysis
13	SAFETY BOOTS SIZE 40	MA	239.00	102.04	MRP	136.96	0.77	EOQ Model
14	ANGLE C/S 1/4" X 2"	MA	288.75	264.20	MRP	24.55	1.37	Separate Analysis
15	WHITE GELCOAT	MA	1,070.50	844.00	MRP	226.50	1.28	Separate Analysis
16	SAFETY BOOTS SIZE 41	MA	179.75	67.58	MRP	112.17	0.79	EOQ Model
17	ANGLE C/S 1/4" X 2"	BG	236.25	192.85	MRP	43.40	1.35	Separate Analysis
18	FLANGE SLIP ON 6"	MA	252.25	174.13	MRP	78.12	2.58	Separate Analysis
19	SUPER NYLON ROPE	MA	298.75	42.83	MRP	255.92	1.93	Separate Analysis
20	GALVANIZED STEEL SHEET	MA	156.50	137.64	MRP	18.86	3.63	Separate Analysis
21	WELDING 3/32"	BG	1,968.50	1,775.72	MRP	192.78	0.98	EOQ Model
22	SAFETY BOOTS SIZE 41	BG	88.50	0.09	MRP	88.41	0.85	EOQ Model
23	NON-CONDUCTING TAPE	MA	682.75	504.79	MRP	177.96	0.98	EOQ Model
24	FREON 22	BG	1,730.25	1,289.00	MRP	441.25	1.15	Separate Analysis
25	PLATE C/S 1/4" X 2"	MA	1,037.25	510.72	MRP	526.53	2.16	Separate Analysis
26	PIPE C/S 1" SEAMLESS	BG	491.74	357.81	MRP	133.92	2.45	Separate Analysis
27	SCREW HEX GALVANIZED	BG	6,382.50	6,291.40	MRP	91.10	4.44	Separate Analysis
28	CABLE	MA	1,397.25	1,164.60	MRP	232.65	4.11	Separate Analysis
29	PIPE C/S 1" SEAMLESS	MA	429.42	310.08	MRP	119.35	1.82	Separate Analysis
30	ARMORED GLASS	MA	2.50	2.26	MRP	0.24	7.00	Separate Analysis

31	CABLE	BG	451.25	307.98	MRP	143.27	2.24	Separate Analysis
32	SCREW HEX STAINLESS	MA	1,614.25	1,575.07	MRP	39.18	3.32	Separate Analysis
33	NYLON ROPE 3/4"	MA	52.00	38.78	MRP	13.22	4.93	Separate Analysis
34	STONE FOR FRICTION	MA	1,280.25	1,090.70	MRP	189.55	1.00	EOQ Model
35	BEARING	BG	31.50	21.85	MRP	9.65	1.33	Separate Analysis

Table 18. Items Analysis Summary

2. Demand Issues

There is much variation in the demand across different years. Some variation is caused by the distinctiveness of vessels (which require different items), and even if they require the same kind of items, they might require different models. Another reason for this variation is that some projects (like shipbuilding and overhauling) last more than two years, or span different periods; this leads to demand being governed by the schedule of the project. For instance, an overhauling project of changing engines and fresh water system for a vessel may be divided across years. So, the demand for engine spares and equipment may be scheduled this year and the demand for fresh water pumps may be scheduled next year. This causes a disproportionate demand from one year to another.

There are some specific items that are needed for a specific vessel or project, and then, not needed again for a while. For instance, submarine spare parts are only required once every several years in COTECMAR; but when they are required, they are required in high quantities with some urgency.

Due to technology advancements or the practicality of an item, the demand of some items grows significantly over the years and the demand of others decreases significantly over the years. Therefore, this will affect the average demand and make it harder to make good forecasts of demand.

3. Price Issues

There is variation in the prices without any constant pattern. There is no regular increase over time; instead, sometimes the prices go down due to negotiation.

Some outlier prices have an effect on the average price. Most of these outlier prices are due to a sudden change of supplier for reasons like urgent need, or stockout of the regular supplier. Other outlier prices are created by typos. These kinds of typos are easy to check because such values are surprisingly high, and we can see how the same supplier offered us the regular correct price on very close dates.

There is lack of data for certain items in some POs, because they are supplier consignments. Thus, most of the information, such as average price, is based only on warehouse transactions.

4. Item Issues

Some items are sold in different packaging (one liter or half liter), but this condition (which makes them different SKUs) does not affect the usage for production purposes. For example, the item CATALYST FOR POLY EPOX comes in two different packages. One comes in a ¼ gallon container and the other comes in a $^{1}/_{8}$ gallon container. Therefore, we need to take into account both packages in order to get a unified demand in gallons.

5. Lead Time Issues

The standard deviation of the lead time is high in some items because of outlier cases that happen every once in a while. Lead times for the same items are mostly close to each other; however, in rare instances there is a drastic change in lead times due to extraordinary events.

There is lack of information for some items, especially in the receiving dates of the inventory. Sometimes the same items have no receiving dates in some purchase orders, and have a receiving date on other purchasing orders. This is caused by consignments that are signed with vendors where they have items in COTECMAR's warehouse, which makes the lead time zero. In some instances, vendors are out of that item, which necessitates ordering more from other suppliers. This creates a non-zero lead time.

6. Process Issues

In the Warehouse Transaction file, we find that the warehouse employees, instead of registering returns from investment and administrative projects with the correct transaction code (RS), they type negative deliveries. This means that there is no standard process for the same transaction even when they come from different projects.

We find many returns by the projects in the data. In some cases, the projects return the complete quantity or more than half of what they asked for. Sometimes, they do so in order to have extra stocks during the works, to avoid delay in case they need more. Sometimes it is due to lack of planning or inaccurate calculation of their needs. This situation may create unnecessary stockouts, and fake alerts of replenishment needs.

E. SUMMARY

This chapter covered the determination of the needed variables for inventory management calculations. We calculated annual demand and separated the dependent and independent demand items quantities. We calculated order lead times and refined the data from outliers. Then we calculate holding cost per unit, fixed cost per order and shortage cost per unit.

This chapter included discussion of different inventory models, along with the assumptions related to each one and the selection of the basic EOQ model for independent demand items quantities that have CV equal or lower than one. Furthermore, in this chapter, we apply the data of the selected items in all of the equations. Finally, all of the findings are listed. In the following chapter, working from these calculations and findings, we present conclusions, recommendations for management, and suggestions for future research.

V. CONCLUSIONS AND RECOMMENDATIONS

This chapter is presented in three parts. The first part contains our conclusions, the second part presents our recommendations for management, and the last part contains our suggestions for future research.

A. CONCLUSIONS

We categorize our conclusions into demand, lead time, general inventory management issues, and calculation results. The following are the conclusions.

1. Demand Conclusions

Based on the demand data, we find that about 40% of the inventory is independent demand items. The remaining 60% of the inventory is dependent demand items that must be treated using processes such as MRP. This is a normal circumstance for an industry (like a shipyard) that performs different business functions, where a big portion of their business comes from planned projects such as shipbuilding or overhauling in which replenishments can be planned in advance. The 40%, that are independent demand items, come from business functions like ship repair and maintenance. Here the demand is not known in advance and EOQ models may be applicable. However, even when we may apply any strategy to a certain portion of the demand, there is a need for a suitable inventory strategy for the other portion of the demand as well.

We conclude that a major portion of COTECMAR demand, which is dependent, may be managed with some approaches such as the MRP described in this project. However, the Bill of Materials list, from an MRP approach, will vary from project to project. This is true even when ships are to be built with the same general specifications. This happens due to constant technology improvement and differences in customer requirements. Furthermore, item demands resulting from overhaul projects are completely different depending on which vessel the shipyard is working on.

2. Lead Time Conclusions

We find in the lead time data that there are some outliers that greatly affect the lead time average, and especially the standard deviation of the errors of forecasts. Although the outlier lead time is a reality in every corporation, taking account of it affects both the service level and the decisions about when and how much replenishment is required, thus distorting the calculations. One example is when production employees send a request directly to the supplier instead of following the regular channel. Once the item arrives at the warehouse, the warehouse does not accept it because there is no purchase order. This leads to all the paper work being done in one day. This gives such items a specific lead time of zero or one day, thus distorting the actual lead time.

Another example is the case in which a supplier experiences unusual circumstances, like a sudden stockout and in which they must ask for an extension in the delivery time, thus distorting the actual lead time. In this case, the purchasing division buys from any other supplier, giving continuity to replenishment. These are both examples of unique situations that do not have to affect decisions based on lead times, because they do not happen under normal situations.

3. Inventory Management Conclusions

In the beginning of the literature review we explained two known classification models. These models are analyzed in order to see if they are suitable or applicable to the shipyard. We find that Kraljic model is useful when there are purchasing portfolio decisions to be made. ABC model is useful for simple inventory management models using EOQ. However, after our research progressed and after analyzing the findings, we conclude that the Kraljic and the ABC models are not suitable for COTECMAR's inventory management. Instead, a more suitable approach is to classify items by whether they are Dependent- or Independent-demand items, and to use EOQ approach for items with low coefficient of variation in demand.

It is necessary to determine a strategy that might be suitable for all of the items regardless of the final user in order to standardize the purchasing process for items that may be needed for regular or sporadic projects.

Even when the Bill of Materials is different between projects, it is important to have a standard Bill of Materials for the kinds of projects we operate. This standard BOM must allow for adjustment according to the characteristics of the vessel and the particular requirements of the works.

Given the characteristics of the demand (its variability and how a group of projects drive it), an inventory management approach could be, at some point, between the MRP and EOQ models. Any such hybrid strategy should consider these two approaches.

Most of the calculated EOQs are very low quantities with an average proportion of 2% out of the total annual demand. This happens because of the very low fixed ordering cost compared to the holding cost. Thus, the equation suggests having many order cycles each year. Although this might be favorable in terms of cost, it could lead to an unrealistic working and processing overload for replenishment. This EOQ model takes into account all measurable costs; but it will be beneficial to determine a way to measure opportunity costs or intangible costs incurred by processing orders, in order to balance the order quantities. For example, a purchasing employee that processes 1000 orders per year could process 500 orders and invest the spare time doing some research beneficial for the company, even when the economic order quantity suggests 1000 orders. The result could be that the engagement of this employee in research could make an improvement that has a higher value to the company than the holding cost savings created by using the EOQ.

The calculated service level is very high in all the items which are around 99.99%. This happens because of the low order quantities we calculated. These computations suggest that replenishments will be done very often, so the risk of a stockout is very low. The longer the replenishment cycle is, the higher the risk of stockout. The origin of this situation is the proportion of holding cost versus fixed order costs. Therefore, if the action explained in the previous paragraph is taken, then the final result will be a more feasible service level.

The calculated reorder point is also very high for all of the items. This is driven by high variability of demand and lead time, and the extremely high service level. We can see that, from the beginning of our calculation, we observe low EOQs which had a direct effect on the service levels and the order points. The order point calculation suggests keeping high inventory levels—enough to cover the high variability. This has pros and cons: the pros include decreasing the risk of stockouts; however, the cons include high holding costs and obsolescence in some items.

4. Conclusions about Results of Calculations

The first issue we observe is that there is a problem with the calculation of the fixed ordering cost because this low fixed ordering cost is leading to low values of EOQ and, consequently, high values of SL and ROP. Therefore, it is important to include opportunity ordering costs and intangible ordering costs to show not only an optimal economic calculation, but also feasible, realistic, and manageable workload quantities that fit in a normal replenishment process.

The second issue is the characteristic of the demand itself, due to uniqueness of the shipyard industry, because the historical data does not provide normal standard deviations. It is also difficult to conduct a forecast based on the historical time-series data, due to the variability and uniqueness of each project. Therefore, it is necessary to create a forecasting method that is not solely based on historical data, but also includes: markets, the types of vessels of the shipyard customer, and the kind of repairs requested by the customers or conducted by the shipyard.

B. RECOMMENDATION FOR MANAGEMENT

A suggestion for management is to improve the information-sharing process between the shipyard and the customers, in order to make better decisions on inventory levels and replenishment cycles. One way to improve this process is to establish one-to-one communications between the customer ship engineers and COTECMAR engineers that will help the shipyard to improve predictions on what items are needed for repair. This procedure should be standardized and formalized, in order to take this information as the replenishment input for the purchasing department. This formality creates accountability and avoids over-ordering materials when they are not needed. The shipyard could start this process with its biggest customer, the Colombian Navy. It would be easier to start with them because COTECMAR is mainly owned by the Navy. Once the shipyard demonstrates the benefit of this process with the Navy, it can implement the same process with private customers. This process could deliver more accurate and economic stock levels with high service levels.

Another suggestion to management is to continuously upgrade the information system (ERP) in the shipyard as technology advances, so that it will be able to rely on more effective systems that will decrease the need for keeping inventories. A good data resource will also reduce the inaccuracy in demand calculations and forecasts. This will help to reduce the need for safety stocks. Furthermore, agreements and relationships between the shipyard and its suppliers should be improved. The improvement could be sharing information on a timelier basis for making better managerial decisions. This could lead to decreasing lead times (and lead time variability) and lowering expediting and processing costs, which can have a significant effect on improving inventory management. Moreover, the information should be implemented across the entire supply chain to timely manage information about demand. This is done so suppliers can anticipate replenishment needs without having to wait until the information goes through the complete supply chain. This delay creates a loss of time and a bullwhip effect, which leads to overstocks and obsolescence in materials.

After progressing in our research, we find that the shipyard industry has distinct traits that are different from most other industries. In other industries historical data, cases of seasonality, patterns, and drivers provide fairly accurate information about demand, which makes applying inventory management easier. However, the shipyard industry is completely different from the regular ones. It has thousands of items, extreme variability of demand over time, regularly changing products due to technology advancements, multiple systems in single ships (propulsion, furniture, hull), and different requirements for each ship.

Management should look into doing more analysis into the demand requirements based on the kind of ships coming in for repair rather than predicting demand based time. A conclusion in this research is that demand is strongly related to the kind of ships being repaired, without following time-based patterns. Therefore, this demand analysis could be done by gathering historical data of the ships that have been in the shipyard. Then, the demand for the most common types of ships can be analyzed in order to determine similarities in the items demanded, or if there are existing patterns. This information could be useful in order to forecast possible items that might be needed once the shipyard knows about an upcoming ship. For this particular industry, this demand forecast could result in more accurate results than forecasting demand based on time.

C. SUGGESTIONS FOR FUTURE RESEARCH

There are some cons and pros to using both continuous and periodic review. Periodic review could be less expensive in terms of reviewing costs and reviewing errors. On the other hand, under continuous review the safety stock needed to provide the same customer service level is lower; thus, overall holding costs are less expensive. It will beneficial to conduct a cost benefit analysis to compare these two review methods in order to implement the optimal method in the corporation.

This project focuses on items that were under continuous review. Therefore, future research on determining the optimal replenishment quantities for consignment inventories would be beneficial. This kind of inventory follows a periodic review process, but is interrupted on every stockout. An optimal quantity will allow for having replenishments in the determined periods, and it will also avoid the violation of the periodic review basic principle.

This project focused on items that were independent and looked into EOQ models to manage them. Since the majority of items were dependent in this industry and EOQ models are not applicable, it would be beneficial for other researchers to focus on strategies to manage dependent items. This will entail more detailed research on MRP approaches that deal with thousands of distinct items for each project, as this is normal in shipbuilding projects.

This project determines demand based on time, which shows that shipyard industries require demand of items with a high variability between different periods. Most of this variability is driven by the characteristics of the ships rather than the periodicity of the works on these ships. It might be beneficial in future projects to show demand based on ships rather than time. This might lead to more accurate demand forecasts and reduce variability of demand.

In this project, we find the parameters needed to determine service levels based on the optimal number of stockout occasions and the number of exposures to stockout for each item each year. However, we recommend applying these models to a larger sample in order to determine if that is the service level desired for management.

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